

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-280 663

State-of-the-Art Study Demilitarization of Conventional Munitions

American Defense Preparedness Association, Washington, D C

Prepared for

Industrial Environmental Research Lab - Cincinnati, Ohio

Feb 78

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA-600/2-78-012	2.	3. REPORT'S ACCESSION NO. PB280663
4. TITLE AND SUBTITLE State-of-the-Art Study: Demilitarization of Conventional Munitions		5. REPORT DATE February 1978 issuing date
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) N. I. Shapira, J. Patterson, J. Brown and K. Noll		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS The American Defense Preparedness Association Union Trust Building 15th & H Street, NW Washington, DC 20005		10. PROGRAM ELEMENT NO. 1BB610
		11. CONTRACT/GRANT NO. 804401
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Lab-Cin., OH Office of Research and Development U. S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE EPA/600/12
15. SUPPLEMENTARY NOTES		
16. ABSTRACT This study was undertaken: To review the technology in use by the military to dispose of obsolete, excess and unsafe explosives and propellants; to characterize, at least in a preliminary manner, the air, water and solid wastes generated during such operations; to identify technology in use or under development to control or eliminate the environmental insult from these operations; and to identify areas where additional research may be needed to more fully characterize the wastes or to develop needed pollution abatement technology. The study found that four basic "demilitarization" techniques are in common use: washout or steamout; confined detonation or burning in a rotary kiln; open burning; and open demolition. More sophisticated processes are under development. Air pollution consists primarily of fine particulates and, to some extent, NO_x from burning or detonation operations. Control is being achieved with scrubbers and bag houses. Water pollution, primarily as dissolved explosives or other components, arises during washout and steamout operations and, to a lesser degree, from the use of scrubbers. Recycle of wastewater is widely practiced as is the use of evaporative ponds. Newer technology is also under development. Solid waste consists primarily of dunnage and scrap shells. Burning of combustibles, resale of scrap metal, and land disposal of sludges are common practices.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Wastewater Explosives Waste Treatment Propellants Manufacturing	Water Pollution Control Air Pollution Control Military Air Emissions	50 B 74 D
18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 143
	20. SECURITY CLASS (This page) Unclassified	22. PRICE A07-A01

EPA-600/2-78-012
February 1978

PB 280 663

Environmental Protection Technology Series

STATE OF THE ART STUDY: Demilitarization of Conventional Munitions



Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

EPA-600/2-78-012
February 1978

STATE-OF-THE-ART STUDY:
DEMILITARIZATION OF CONVENTIONAL MUNITIONS

by

Norman I. Shapira

James Patterson

John Brown

Kenneth Noll

American Defense Preparedness Association
Washington, D. C. 20005

Grant No. R-804401

Project Officer

Herbert S. Skovronek

Industrial Environmental Research Laboratory - Cincinnati
Edison, New Jersey 08817

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

For sale by the Superintendent of Documents, U.S. Government
Printing Office, Washington, D.C. 20402

j.a

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory-Cincinnati (Edison, NJ field station), U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-CI) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

The report reviews the technology currently in use by the military for disposal of obsolete, unsafe, and excess explosives and propellants and, to the extent possible, characterizes the air, water, and solid wastes generated by these operations. The study outlines the present environmental problems of the industry, the technology in use to control these problems, and the research needed to upgrade the pollution abatement technology. In addition to being directly pertinent to the explosives industry segment of EPA's R&D program, many of the concepts and technologies noted may have wider bearing on pollution abatement in other chemical industry segments. The Industrial Pollution Control Division should be contacted for further discussion of this project.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

This is the second State-of-the-Art Study conducted for EPA by the American Defense Preparedness Association. The first study, entitled "Military Explosive and Propellants Production Industry" (EPA 600/2-76-213), dated October 1976, presents a detailed description of military explosives and propellants, as well as the processes for their manufacture and pollution abatement practices. The reader is referred to this prior study for basic background information.

The purpose of this summary is to summarize preliminary conclusions and recommendations, which are as follows.

DEMILITARIZATION PROCESSES

Although complete conclusions and recommendations are not within the scope of this Phase I Report, nevertheless some brief, preliminary conclusions can be drawn regarding the demilitarization processes and the effluents produced therefrom. This section deals only with the processes themselves. Preliminary conclusions regarding treatment are presented in subsequent paragraphs. Six categories of demilitarization are addressed in this section: washout; deactivation furnace; open detonation; open burning; new developments; and advanced technology in chemical demilitarization.

a. Washout

This is an effective process for removal of most explosives, such as TNT and Comp B. It is not effective for removal of many propellants as in rocket motors, or plastic bonded explosives (PBX). In addition, this is an energy-intensive process. Under the present circumstances of decreasing supply and increasing cost of energy, alternative processes should be investigated to minimize energy consumption.

b. Deactivation Furnace

This is an effective process for demilitarization of small munitions. Although energy consumption is involved, safety is

also a paramount consideration, and this may be judged as the most cost-effective process for small munitions demilitarization when all considerations are taken into account.

c. Detonation

This is a simple, safe and cost-effective process for demilitarization of many munitions which are obsolete, or unsafe to handle otherwise. No additional energy consumption is involved. The quantities involved are small when compared with the commercial blasting industry (over one million tons/year) (129). Use of this process will always be required to a certain degree.

d. Open Burning

This is also a simple, safe and cost effective process for demilitarization of munitions which are obsolete or unsafe to handle otherwise. Potentially adequate alternatives to open burning are under development, and their implementation will depend upon the relative balance among cost, energy implications, and environmental factors.

e. New Developments

Current military plans for development and demonstration of new or improved demilitarization processes are sufficiently comprehensive to provide a range of alternatives, provided that adequate funding is made available for the implementation of these development programs. A potentially useful study could be initiated to examine systematically the energy implications, environmental aspects and cost effectiveness of various alternative new demilitarization development programs. This would be a program which would merit EPA funding support.

f. Advanced Technology

The U. S. Army has developed and demonstrated at Rocky Mountain Arsenal and Tooele Army Depot the most advanced technology presently available for the safe disposal of energetic, toxic and hazardous substances. A potentially useful program could be initiated by EPA to investigate the application of this technology to the disposal of toxic and hazardous industrial substances as contemplated in the recently enacted legislation in PL 94-469.

TREATMENT OF AIR EFFLUENTS

With respect to the major current demilitarization processes, the following preliminary conclusions can be drawn with respect to air effluents.

a. Washout

Although minimal amounts of explosive may escape through the scrubbers in the APE 1300 washout plant, this is not considered to constitute an environmental problem.

b. Deactivation Furnace

Addition of the APE 1276 fabric filter particulate collection system to the APE 1236 deactivation furnace constitutes a significant improvement in air pollution control and should satisfy environmental quality standards.

c. Detonation

Until the same environmental criteria are applied to the use of explosives in the commercial blasting industry, there is no reasonable basis for criticism of demilitarization of obsolete or unsafe munitions by detonation. Principal products appear to be CO_2 , H_2O and N_2 , all of which are non-pollutants. Covering of the munitions by earth substantially reduces noise and particulates.

d. Open Burning

Alternatives to open burning are in various stages of development, and given sufficient funding, should provide adequate options for the elimination of the environmental problems associated with this process. These alternatives are reviewed in Chapter III. Support of these development efforts by EPA funding is recommended, as well as more detailed evaluation of alternative processes.

e. Advanced Technology

The air pollution control systems in use at Rocky Mountain Arsenal and Tooele Army Depot constitute the most advanced technology currently available for treatment of air effluents associated with the safe disposal of toxic and hazardous materials.

EPA should take an active role in technology transfer in applying this technology to the solution of problems in industry.

TREATMENT OF WASTEWATER

The APE 1300 hot water washout system is the only major demilitarization process with potential for water pollution (pink water), and the degree of potential pollution varies with the terrain and climatology of the facility. Development programs encompassing carbon column and polymeric resin treatment, under investigation by several Army and Navy organizations, will provide effective treatment technology if adequately funded and properly designed. In addition, new processes are under investigation which involve pretreatment for removal of suspended solids, as well as total dissolved solids. These would permit significant opportunities for water re-use. High pressure cold water washout is also an alternative with potential advantages for energy savings. Continued evaluation of alternative options is recommended.

SOLID WASTES

Additional study is needed to determine whether solid wastes from demilitarization constitute an environmental problem, and, if so, to what degree.

ABSTRACT

This study was undertaken:

To review the technology in use by the military to dispose of obsolete, excess, and unsafe explosives and propellants; to characterize, at least in a preliminary manner, the air, water and solid wastes generated during such operations; to identify technology in use or under development to control or eliminate the environmental insult from these operations; and to identify areas where additional research may be needed to more fully characterize the wastes or to develop necessary pollution abatement technology.

The study found that four basic "demilitarization" techniques are in common use: washout or steamout; confined detonation or burning in a rotary kiln; open burning; and open demolition. More sophisticated processes are under development.

Air pollution consists primarily of fine particulates and, to some extent, NO_x , from burning or detonation operations. Control is being achieved with scrubbers and baghouses.

Water pollution, primarily as dissolved explosives and other components, arises during washout and steamout operations and, to a lesser degree, from the use of scrubbers. Recycle of wastewater is widely practiced as is the use of evaporative ponds. Newer technology is also under development.

Solid waste consists primarily of dunnage and scrap shells. Burning of combustibles, resale of scrap metal, and land disposal of sludges are common practices.

This report was submitted in fulfillment of Grant No. R-804401 by an AdHoc Committee of The American Defense Preparedness Association under the sponsorship of the U. S. Environmental Protection Agency. The report covers the period of March 1976 to March 1977, and work was completed as of August 1977.

CONTENTS

Foreword.....	111
Preface	iv
Abstract.....	viii
Figures.....	x
Tables.....	xi
Acknowledgments.....	xiii
Introduction.....	1
Demilitarization Processes and Equipment.....	9
Standard processes in general use.....	9
Processes in local use.....	21
Processes under development.....	24
Current demilitarization facilities.....	31
Planned new demilitarization facilities.....	34
Special demilitarization facilities.....	38
Preliminary conclusions and recommendations.....	43
Air Effluents.....	46
Air pollution sources and characteristics.....	46
Air pollution control.....	58
Review of development trends in explosives and propellants waste incineration.....	70
Economic analysis.....	75
Preliminary conclusions.....	80
Wastewater Effluents.....	83
Wastewater sources and characteristics.....	83
Wastewater treatment and disposal.....	94
Solid Wastes.....	107
References.....	113
Appendix - English/Metric Conversion Table.....	125

FIGURES

<u>Number</u>		<u>Page</u>
1	APE 1300 Explosive washout plant schematic diagram.....	12
2	APE 1300 Water reclamation system.....	13
3	APE 1300 Photograph of washout section.....	14
4	APE 1236 General assembly.....	16
5	APE 1236 Discharge assembly.....	17
6	Demilitarization locations.....	32
7	Western Demilitarization Facility, Naval Ammunition Depot, Hawthorne, Nevada.....	35
8	Pilot model air pollution control system.....	61
9	Process diagram - DARCOM depot disposal system....	65
10	Comparison of operating costs (250 lb/hr).....	78
11	Comparison of operating costs (1000 lb/hr).....	79
12	APE 1300 Water reclamation system.....	97
13	Basic selection chart carbon vs. resin.....	106

TABLES

<u>Number</u>		<u>Page</u>
1	Military Demilitarization Installations.....	2
2	Principal Ingredients of Explosive and Propellant Formulations.....	4
3	Uncontrolled Emissions for Combustion of Munitions...	48
4	Detonation Products of Confined and Unconfined Explosions.....	49
5	Emissions from Explosives Detonations.....	50
6	Emissions from Burning of Energetic Materials.....	53
7	Estimated Daily Pollution Emissions from Burning Explosives.....	54
8	1975 Monthly Emissions from PEP Waste.....	55
9	1975 Monthly Emissions from PEP-Contaminated Waste...	56
10	Summary of 1975 Emissions.....	57
11	Air Pollution Control System for Deactivation Furnace - Installation Schedule.....	59
12	Particulate Emission Data.....	62
13	Washout Plant Effluent Control.....	64
14	Summary - Developmental Incinerator Systems.....	74
15	Cost Factors for the 250 lb/Hr Case.....	76
16	Cost Factors for the 1000 lb/Hr Case.....	77

<u>Number</u>		<u>Page</u>
17	Munitions Processed in Army Depot Washout Facilities.	84
18	Chemical Characterization of Letterkenny AD TNT Washout Wastewater.....	87
19	*Chemical Characterization of Letterkenny AD Comp B Washout Wastewater.....	87
20	Summary of Washout Wastewater Characteristics.....	90
21	Military Facilities with Steamout Capability.....	91
22	NWSC Crane Scrubber Water Characteristics.....	94
23	Adsorption Capacity for XAD-4.....	101
24	Wastewater Characteristics.....	101
25	Ultimate Disposal Methods for Washout Effluents.....	103
26	Demilitarization Facilities Ultimate Disposal Methods.....	104
27	Economics of Demilitarization Water Pollution Control.....	105
28	Characterization of Cyclone Dust Samples.....	110
29	Characterization of Baghouse Dust Samples.....	111

ACKNOWLEDGMENTS

This study was conducted for EPA by The American Defense Preparedness Association (ADPA) under Grant No. R-804401. The purpose of this paragraph is to identify the principal participants, and their relationships.

a. Sponsor. The study Sponsor was The Office of Research and Development of The U. S. Environmental Protection Agency. The program officer within EPA was Dr. Herbert Skovronek of the Industrial Environmental Research Laboratory, at Edison, New Jersey.

b. ADPA. The American Defense Preparedness Association assembled an AdHoc Committee from the industrial and educational communities for the specific purpose of conducting this study.

c. Department of Defense. The study would not have been possible without the full cooperation of the Military Services, and their support was generously and enthusiastically provided, specifically by the following commands:

- (1) Headquarters, U. S. Army Materiel Development and Readiness Command (DARCOM)
- (2) Headquarters, U. S. Naval Material Command
- (3) Joint Conventional Ammunition Program Coordinating Group (JCAP)
- (4) Headquarters, U. S. Army Armament Command
- (5) Headquarters, U. S. Navy Sea Systems Command
- (6) U. S. Army Environmental Hygiene Agency

This study is based substantially upon data and factual information provided by the Military Services.

d. In particular, the following persons are cited for their valuable and significant contributions:

- (1) Mr. John Pace, Environmental Control Office,
Headquarters, U.S.A. DARCOM
- (2) Mr. Edward J. Jordan, Executive Director, JCAP
- (3) Mr. Daniel Quagliarello, Headquarters, U. S. Naval
Material Command
- (4) Mr. Kenneth Range, Demilitarization Coordinator,
Headquarters, U. S. Naval Sea Systems Command
- (5) Col. A. D. Kneesy, U. S. Army Environmental Hygiene
Agency
- (6) Mr. John Byrd, U.S.A. DARCOM Ammunition Center,
Savanna, Illinois
- (7) Mr. Frank Crist, U. S. Army Ammunition Equipment
Office, Tooele, Utah

CHAPTER I

INTRODUCTION

1. BACKGROUND

This study was conducted by the American Defense Preparedness Association (ADPA) for the Office of Research and Development of the U. S. Environmental Protection Agency. This study is one of many which ADPA has conducted for the U. S. Government. The study was initiated in March 1976, and completed in March 1977.

2. PURPOSE

The purposes of Phase I of this study were as follows:

- a. First, to define and characterize the typical air, solid and wastewater effluents from explosives and propellants demilitarization. This has been done primarily by the assembly of data already available within the Military Services.
- b. Second, to identify explosive and propellant air, solid, and wastewater effluent treatment processes, including those now being used as well as those under investigation.

The purposes of Phase II of this study were:

- a. First, to study reports collected in Phase I, collate data, analyze the above mentioned wastewater, air and solid effluent treatment processes and evaluate their effectiveness, and prepare conclusions and recommendations.
- b. Second, to define RD&D programs which EPA might support in order to make available to the explosives and propellants demilitarization industry the most effective and economical treatment technology for achievement of the effluent quality prescribed by the U. S. Congress.

3. SCOPE

The scope of the study can be defined in terms of:

- o Military organizations,
- o Munitions,
- o Demilitarization processes,
- o Effluents, and
- o Treatment technology.

The military organizations are tabulated in Table 1. Demilitarization processes are described in Chapter II. Effluents and treatment technology are discussed in Chapters III-V.

TABLE 1. MILITARY DEMILITARIZATION INSTALLATIONS

U. S. Army Depots (AD)	U. S. Army Ammunition Plants (AAP)	U. S. Navy Installations
Anniston AD	Iowa AAP	NWSC Crane
Letterkenny AD	Ravenna AAP	NAD Hawthorne
Lexington-Bluegrass AD	Joliet AAP	NAD McAlester
Pueblo AD	Cornhusker AAP	NAD Earle
Navajo AD	Newport AAP	NWS Yorktown
Ft. Wingate AD	Longhorn AAP	NWS Seal Beach
Red River AD	Pine Bluff Arsenal	NWS Charleston
Seneca AD	Milan AAP	NTS Keyport
Sierra AD	Kansas AAP	NOS Indian Head
Tooele AD	Lone Star AAP	
Umatilla AD	Volunteer AAP	
Savanna AD	Sunflower AAP	
	Holston AAP	
	Radford AAP	
	Indiana AAP	
NWSC - Naval Weapons Support Center		NTS - Naval Torpedo Station
NAD - Naval Ammunition Depot		NOS - Naval Ordnance Station
NWS - Naval Weapons Station		

a. "Demilitarization" is the process of rendering inert or removing the energetic ingredients contained in munitions which are defective, obsolete, unsafe, or otherwise no longer required in the military inventory. Demilitarization also includes removal of aging inert ingredients when the casings are desired for reuse for refill with new explosives or propellants.

b. The organizations encompassed in this study include: the U. S. Army; the U. S. Navy; and the U. S. Air Force. From Table 1, it can be seen that twelve U. S. Army Depots are included, as well as nine U. S. Navy installations, and fifteen U. S. Army Ammunition Plants. The Army and Navy conduct essentially all demilitarization for the U. S. Air Force.

c. Department of Defense has designated the U. S. Army as "Single Service Manager" for the production, load, assembly and pack of all Army, Navy and Air Force explosives, propellants, pyrotechnics, smokes, and conventional munitions. Demilitarization is included within this Single Service Manager responsibility. As a consequence, NWSC Crane, NAD Hawthorne and NAD McAlester will come under Army cognizance effective in October 1977.

d. The principal explosive and propellant ingredients filled in military munitions are listed in Table 2. In addition, there are primers, detonators, smokes and pyrotechnic formulations.

e. The munitions products included in this study are:

- (1) Bulk explosives and propellants,
- (2) Explosive warheads,
- (3) Rocket motors (propellant),
- (4) Small arms ammunition, and
- (5) Pyrotechnics, smokes and illuminants.

f. The munitions categories are as follows: shell and missile warheads; shell and missile propellants; mines; fuzes; small arms ammunition; grenades; bombs; submunitions; torpedoes.

g. The tasks of Phases I and II are as follows. This report addresses Phase I only.

Phase I

(1) Task I. Identification of Military Installations engaged in demilitarization activities.

(2) Task II. Identification of existing military reports and studies on demilitarization programs.

TABLE 2. PRINCIPAL INGREDIENTS OF EXPLOSIVE
AND PROPELLANT FORMULATIONS

Explosives	Principal Ingredients
Amatol	TNT, NH_4NO_3
Composition A1-A6	RDX, Wax
Composition B	TNT, RDX, Wax
Cyclotol	TNT, RDX
Explosive D	Ammonium Picrate
HEX	RDX, Al, Wax, CaCl_2
H-6	TNT, RDX, Al, Wax, CaCl_2
Minol	TNT, NH_4NO_3 , Al
Octol	HMX, TNT
PBX	RDX or HMX and Polymeric Binder
Tritonal	TNT, Al
Smokeless Powder	NC, NG
Tetryl	
<u>Propellants</u>	
Single Base	Nitrocellulose (NC), DNT
Double Base	NC and Nitroglycerin (NG)
Cross-Linked Double Base	NC, NG, HMX, AP*, Al, Polyurethane
Triple Base	NC and NG and Nitroguanidine
Composite	AP*, Al, Polyurethane or Polybutadiene
Base Grain Casting Powder	NC, NG, HMX, AP

*Ammonium Perchlorate

Al is metallic aluminum in all cases

(3) Task III. Meetings with appropriate senior military program managers concerned with demilitarization, in accordance with authorization provided to the ADPA Ad Hoc Committee by the major Army, Navy and Air Force Commands.

(4) Task IV. Visits to selected military facilities engaged in demilitarization activities to meet with technical and operational personnel and collect first-hand information.

(5) Task V. Collection of data from all available sources.

(6) Task VI. Preliminary assessment report on the environmental problems of demilitarization.

Phase II

(7) Task VII. Collation and evaluation of data by: product; demilitarization process; effluent; and disposal or treatment method.

(8) Task VIII. Identification of data gaps.

(9) Task IX. Derivation of conclusions on the effectiveness of pollution abatement technologies associated with the various demilitarization processes.

(10) Task X. Preparation of conclusions and recommendations for R,D&D programs.

(11) Task XI. Preparation of final report.

4. LIMITATIONS AND EXCLUSIONS

a. Exclusions

Specifically excluded from the scope of this study are the following:

- (1) Inert metal parts,
- (2) Toxic chemical agents, and
- (3) Herbicides.

b. Limitations

This study is limited to the degree that it is based upon available sampling and monitoring data and published documents, supplemented by on-site visits to the extent permitted by time and financial resources. No actual monitoring or sampling was done by the ADPA Committee. In addition, this Phase I study has primarily been a data collection effort. Analysis and evaluation are within the scope of Phase II rather than Phase I, although some preliminary assessments are made in this Phase I Report.

c. References

The reports and documents collected in Phase I of this program are listed in the attached References. Some 131 references were collected. The detailed review and analysis of these documents are not within the scope of this Preliminary Assessment Report.

d. Plant Visits

Visits were made by the Committee to the following military installations for a number of purposes: to observe demilitarization equipment and operations at first hand; to observe equipment used for the treatment/disposal of effluents emitted into the air or water, or onto the land; to be briefed on research and development programs for new demilitarization and waste effluent treatment technology.

Installation--

(1) Army:

Anniston Army Depot, Anniston, Ala.
Letterkenny Army Depot, Letterkenny, Pa.
Red River Army Depot, Texarkana, Tex.
Rocky Mountain Arsenal, Denver, Col.
Savanna Army Depot, Savanna, Ill.
Sierra Army Depot, Sierra, Cal.
Tooele Army Depot, Tooele, Utah
U. S. Army Armament Command, Rock Isl., Ill.
U. S. Army Environmental Hygiene Agency, Aberdeen
Proving Ground, Md.
U. S. Army Materiel Development and Readiness Command,
Alexandria, Va.

- (2) Navy:
Naval Weapons Support Center, Crane, Ind.
Naval Ammunition Depot, Hawthorne, Nev.
U. S. Naval Material Command, Alexandria, Va.
U. S. Naval Sea Systems Command, Alexandria, Va.

- (3) Joint Conventional Ammunition Program Coordinating
Group, Rock Island, Ill.

5. OVERVIEW OF THE MILITARY DEMILITARIZATION PROGRAM

a. Perspective

In March 1972, the Joint Logistics Commanders established the "Joint Panel on Disposal Ashore of Ammunition," to "develop a plan for the disposal of ammunition by ecologically acceptable means" (94). As of June 1972, the total continental U. S. inventory of ammunition for disposal was estimated at 191,000 tons, with a five-year future estimate of 433,000 tons, for a total of 624,000 tons of ammunition to be disposed of during the period 1972-77 (94). Visits to various Army and Navy installations have indicated that extensive demilitarization operations were conducted until 1974-1975, with the result that the backlog of ammunition for disposal has been reduced significantly.

b. Magnitude of Current and Future Inventory

The latest available report (96) places the inventory of ammunition for disposal at 127,000 tons as of 31 December 1975. The Army forecasts a demilitarization workload in the range of 35,000 to 38,000 tons annually through 1981. Adding Navy and Air Force munitions, it is estimated that the annual demilitarization workload will be in the range of 100,000 tons or less. The principal current stocks are at the following Navy locations (Dec. 1975 data) (96):

<u>Location</u>	<u>Tons</u>
NWSC Crane	18,748
NAD Hawthorne	37,105
NAD McAlester	28,296

Stocks at individual Army Depots generally are in the range of 5,000 tons, or less. Figures for the Army and Navy include stocks of Air Force munitions. Tonnages previously cited include the weights both of the energetic ingredients and the

metal casings. The percent of weight attributable to the explosive or propellant component varies considerably, but generally can be considered to be in the range of 30-50% of total weight. The composition of the stockpile awaiting demilitarization varies widely, from small arms ammunition to large bombs and solid propellant rocket motors. Principal energetic ingredients are TNT, RDX, and NC.

c. Demilitarization Geography

The major demilitarization operations are carried out at military depots which are remotely located with respect to large population centers, and which contain large land areas amenable to such activities.

CHAPTER II

DEMILITARIZATION PROCESSES AND EQUIPMENT

Current conventional munition demilitarization operations are rather well standardized and use much the same equipment everywhere. There are a few full-scale processes restricted to one or two depots, and there are several new processes under development for improved demilitarization or pollution abatement performance. Pollution abatement is discussed in subsequent chapters.

SECTION I

STANDARD PROCESSES IN GENERAL USE

No two demilitarization operations are exactly alike, but the vast majority of them can be described by the following composite description of five distinct processes.

6. MUNITION DISASSEMBLY LINES

a. The first step in any demilitarization operation is the disassembly of munitions into components suitable for ultimate deactivation. Fixed artillery ammunition, for example, will have the projectile pulled out of the cartridge case in a special jig, the propellant powder dumped into a collection bin, and the primer removed from the cartridge. The projectile will have the fuze unscrewed and removed, the booster pellet removed and the fuze well liner removed, exposing the explosive fill. 50-caliber machine gun ammunition will be de-linked and the actual ammunition separated from the purely mechanical belt hardware. 20-mm ammunition will usually, but not always, have the projectile pulled, the powder dumped, and the projectiles and cases collected in separate bins, whereas smaller ammunition is usually left intact. Bombs, mines and other large munitions will have the fuzes removed so as to expose the explosive fill in much the same manner as large fixed ammunition.

b. The above operations are typically carried out more or less remotely on automated disassembly lines designed especially for the job. Fixed artillery ammunition, for example, will be placed by hand into a "Vertical Pull Apart Machine" where it is clamped firmly into place. The machine rotates the munition behind a safety shield, and a pair of jaws grip the projectile and pull it forcibly from the cartridge case. The freed projectile is placed (usually by hand) into another clamping jig; and another jaw grips and unscrews the fuze, behind another safety shield. Fuzes go down one conveyor, de-fuzed projectiles down another, empty cartridge cases down still another; and the dumped propellant powder is collected into a bin by vacuum. It is the reverse of an assembly line.

c. The disassembly of smaller ammunition, such as 20-mm, is even more automated. Complete rounds are laid by hand on a conveyor belt which takes them behind a safety shield, clamps the cases firmly while forcibly bending the projectile sideways until it breaks free of the case, drops the projectile onto a second conveyor which takes it to a collection bin, drops the cases into a tumbling barrel where the propellant powder is shaken out and collected in a vacuum system, and finally drops the cases onto a third conveyor which takes them to another collection bin.

d. The components of the disassembly lines are all special items, known as "Ammunition Peculiar Equipment (APE)". There are hundreds of them, ranging all the way from hand-held clamps through conveyor and pullapart units to complete washout plants and radiographic trailers. They are listed and described in detail in an Army publication, "Army Equipment Data Sheets - Ammunition Peculiar Equipment, Technical Manual TM 43-0001-47," dated July 1975. (The Manual also lists ammunition peculiar equipment for purposes other than demilitarization, such as assembly, inspection, dud retrieval and the like.) (86)

e. The munition breakdown and disassembly operations are all purely mechanical, and they involve no air or water pollution discharges except for nominal amounts of dust and/or floor wash-down. Many of them are located in buildings that do not even have water except in the personnel lounges.

7. APE-1300 WASHOUT PLANT

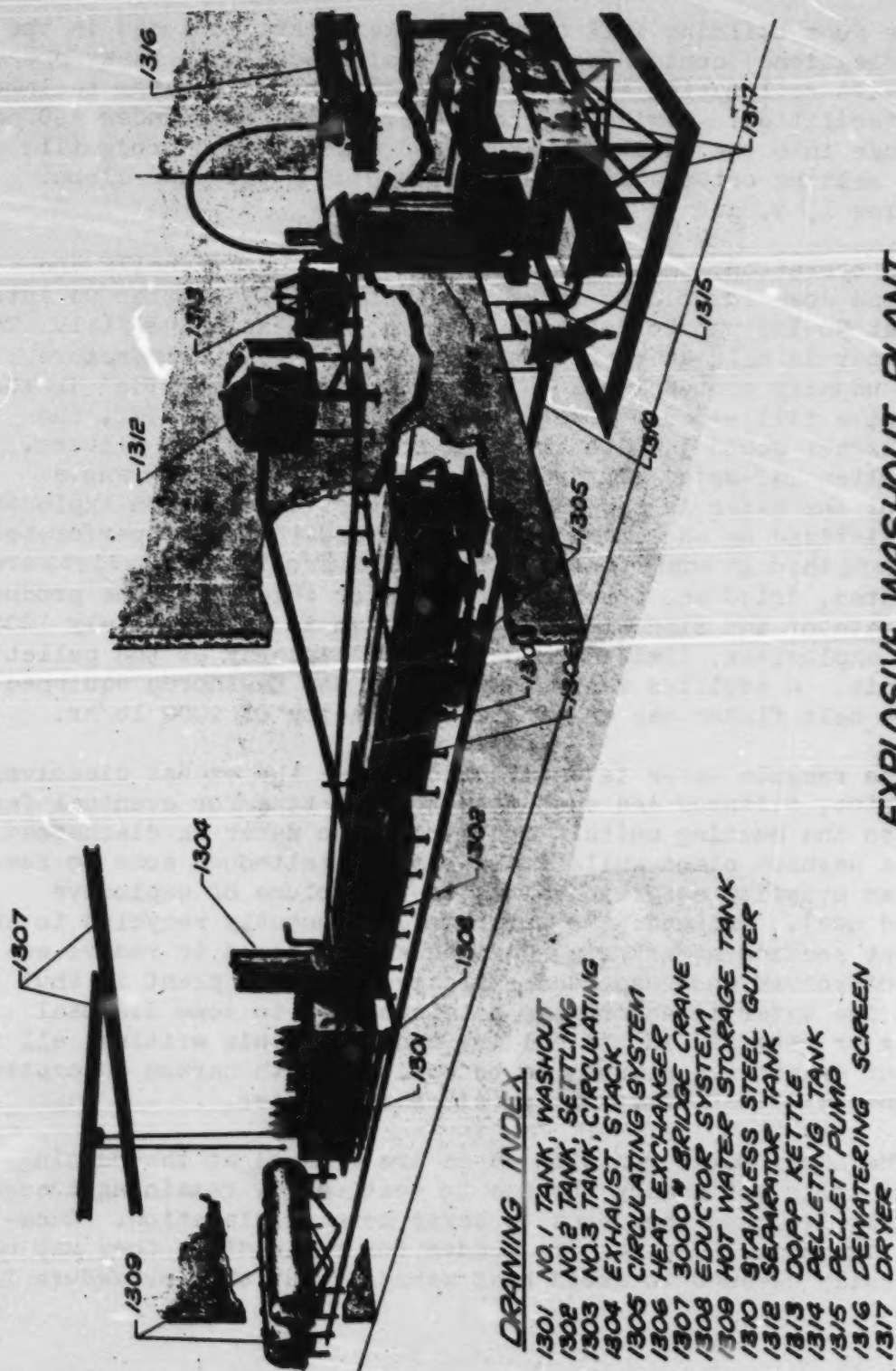
a. The Washout Plant is a standard APE item designed and specified in detail by the U. S. Army Ammunition Equipment Office (AEO) located at Tooele Army Depot. It consists usually of a 4500

square foot building (all of whose details are included in the specifications) containing a water heater, the wash racks proper, explosive reclamation and packaging sections, and water reclamation facilities. Basically, hot water is injected under ~90 psi pressure into the cavity of an opened and up-ended projectile or bomb, melting out the fill and washing the metal case clean. (Figures 1, 2, and 3)

b. In operation, ammunition items are placed vertically and open end down in holding racks, and hot water is jetted up into them at 90-125 psi to melt and wash out the explosive fill. The hot water is held at approximately 180°-205°F, a temperature which usually contemplates TNT as the energetic material in the explosive fill -- much lower would fail to melt the TNT, and much higher would lead to clogging of the flumes and filters. The molten TNT-water slurry is led to a settling tank where most of the water is separated for re-use. The molten explosive is pelletized by showering droplets forced through a perforated plate and through ambient cold water, and the solidified pellets are collected, dried and boxed for storage or shipment. The production rate of the standard APE-1300 system is approximately 1400 lb/hr explosives, limited mainly by the capacity of the pelletizing unit. A modified washout system at NAD Hawthorne equipped with a belt flaker has an estimated capacity of 2000 lb/hr.

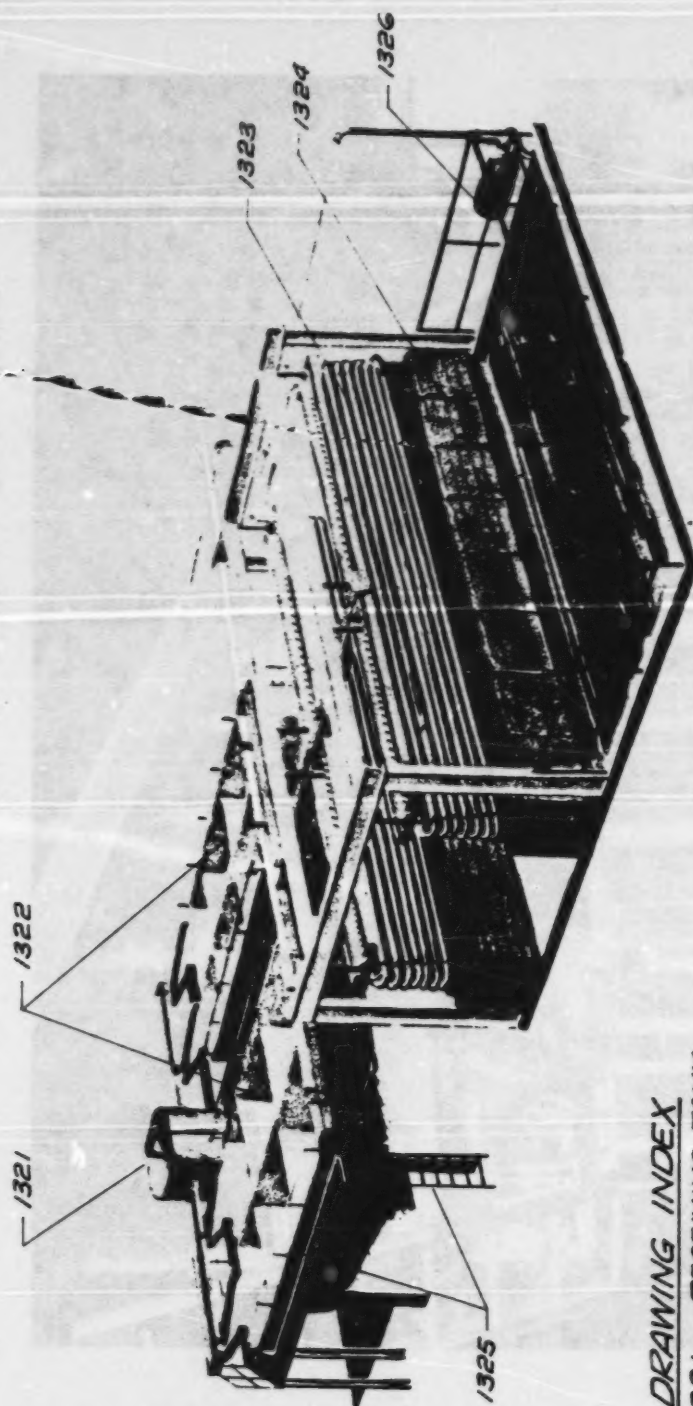
c. The recycle water is chilled to remove the excess dissolved explosive, filtered and sent to a holding tank for eventual feed back to the heating units. Ordinarily, no water is discharged from a washout plant while it is running (although some do feature an overflow equal in volume to the volume of explosive washed out). Instead, the water is continuously recycled to the washout section after being chilled and filtered to remove excess dissolved and suspended explosive. When a plant is shut down, the water inventory may be discharged to some disposal system or retained in the holding tank. At this writing, all the washout plants are planned to be equipped with carbon adsorption columns for final treatment of discharged water.

d. The empty metal munition cases are flashed at the burning ground or in a flashing furnace to destroy any remaining traces of explosive, and then sent to scrap metal reclamation. Occasionally, when the cases are needed for re-loading, they may be chemically cleaned to avoid heat warpage; but this procedure is unusual.



EXPLOSIVE WASHOUT PLANT

Figure 1 - APE 1300 Explosive Washout Plant Schematic Diagram. (130)



DRAWING INDEX

1321 RECEIVING TANK
1322 SETTLING TANK
1323 COOLERS
1324 FILTERS
1325 CATWALK & LADDERS
1326 PUMP, CENTRIFUGAL

EXPLOSIVE WASHOUT PLANT WATER RECLAMATION SYSTEM

Figure 2 - APE 1300 Water Reclamation System. (130)

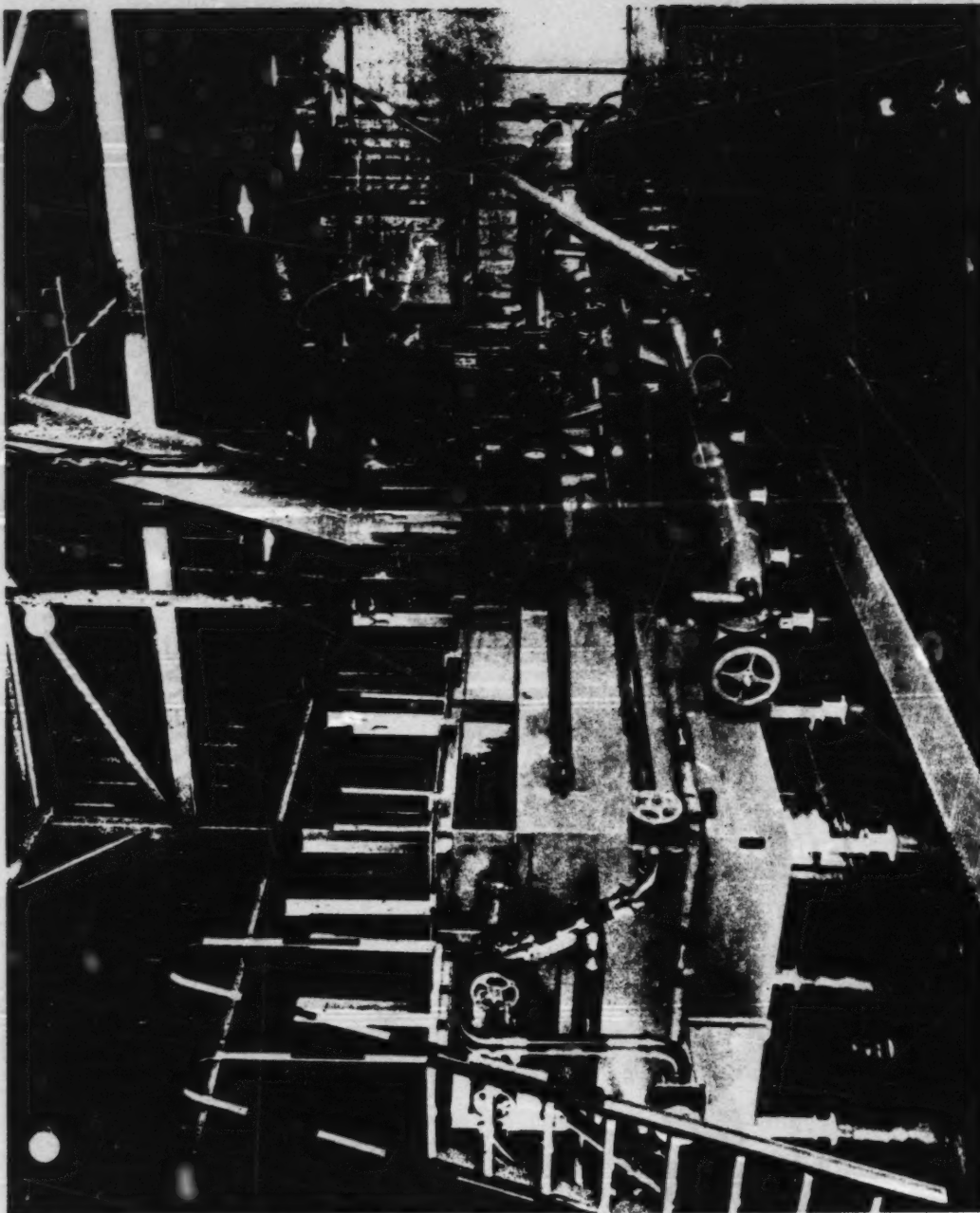


Figure 3 - APE 1300 Photograph of Washout Section. (130)

e. Loaded filter batts and unreclaimable dregs from the explosives settling tanks are disposed of by burning, either on a burning ground or in a suitable incinerator.

f. The APE-1300 Washout system has been demonstrated for explosive fills of TNT, Comp B (TNT-RDX), Tritonal (TNT-Al⁰), Amatol (TNT-NH₄NO₃) and Octol (TNT-HMX). The TNT, the Comp B and the Tritonal were successfully pelletized. The Octol solidified "too fast and too hard", but it could have been flaked or otherwise reclaimed. The Amatol was an experimental run; the system is not approved for ammonium nitrate-containing compositions because of corrosion of the brass fittings in the plant.

g. At this writing, most of the APE-1300 Washout plants are in layaway for lack of a workload. The older ones are being modernized by the addition of such refinements as W-bottom tanks to handle Comp B, twin settling tank eductors and water-flushed pump seals; and all of the plants are expected to be equipped eventually with carbon column final water filters.

h. The APE-1300 system is described in detail in an Army Technical Manual, "Operation and Maintenance - Ammunition Explosives Washout and Reclamation System - APE 1300," Revision No. 2, 1 February 1974. (5). Air pollution is discussed in Ch. III.

8. APE-1236 DEACTIVATION FURNACE

a. The APE-1236 "Deactivation Furnace" is a steel rotary kiln approximately 30 feet long and four feet in diameter. (Figures 4 and 5). The main body is a horizontal tube (four 60" sections bolted end to end) with side walls about 2-1/4 inches thick and with a spiral internal flight which acts like a screw conveyor in moving materials through the unit as the tube slowly rotates. Items such as small arms ammunition, artillery shell fuzes, emptied 20-mm cartridge cases and the like are fed to the furnace via a steel conveyor belt which carries them high above the mouth of the furnace and drops them down a chute into the feed end of the rotating tube. An oil or gas fired burner in the discharge end of the tube provides a flame and hot flue gases which sweep through the tube and up a stack mounted over the feed end. The temperature near the burner is about 1200°F; it is about 600-900°F in the middle sections and about 400-500°F in the stack.

b. As the items being demilitarized are carried through the tube by the spiral flight, any explosives they contain deflagrate or detonate as they reach their kindling or initiation temperatures.

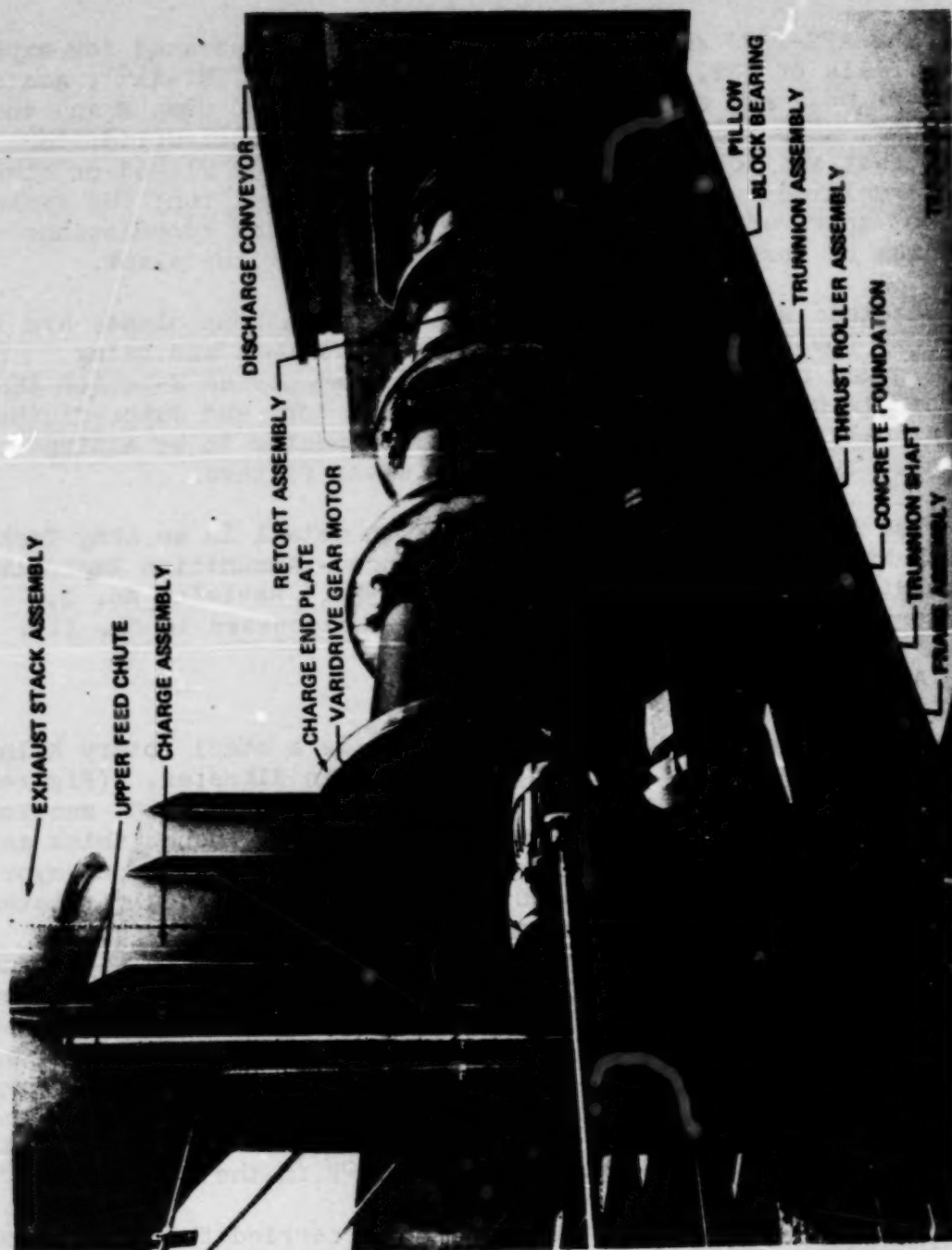


Figure 4 - APE 1236 General Assembly. (83)

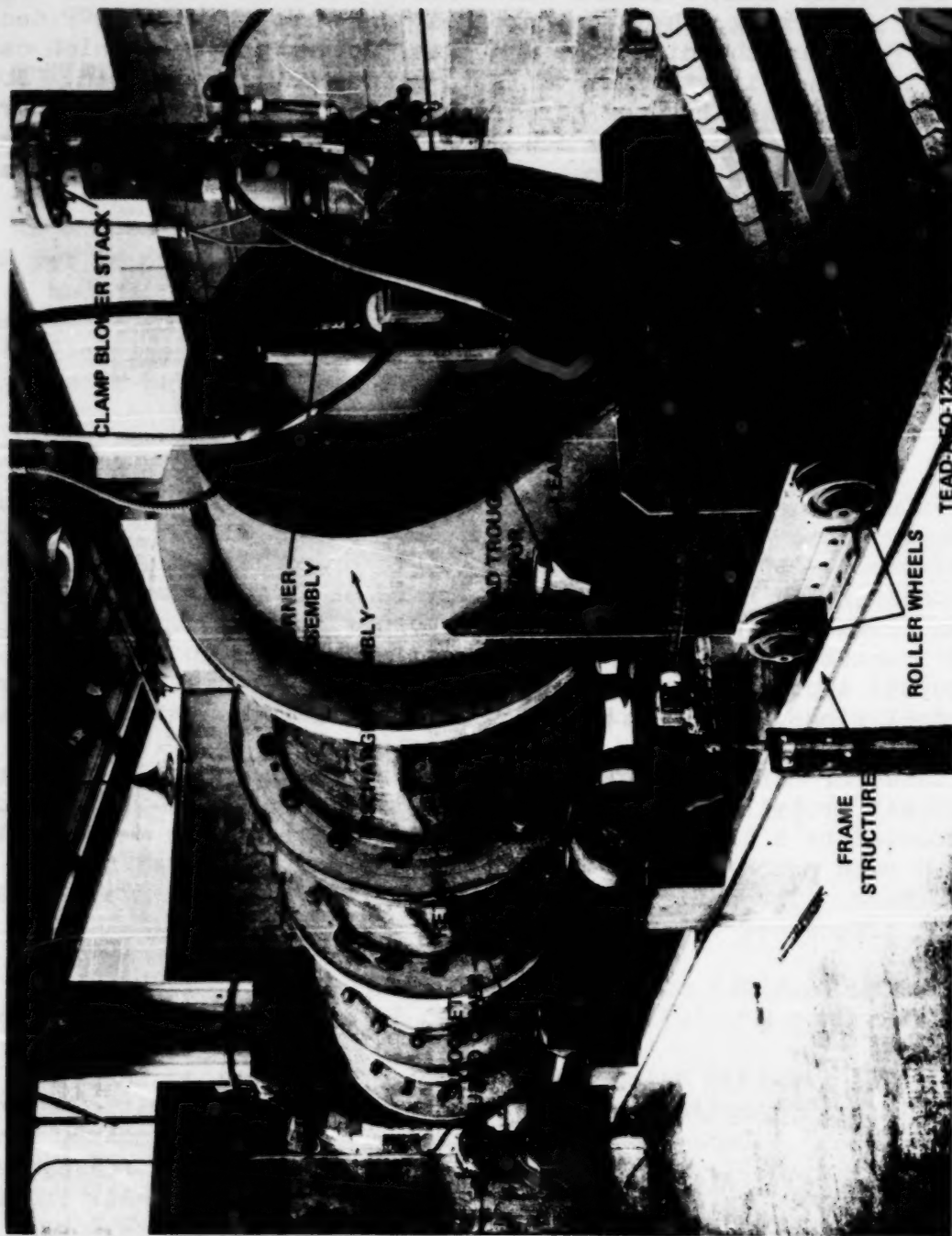


Figure 5 - APE 1236 Discharge Assembly. (83)

The furnace operating speeds are adjusted so that this happens approximately in the center of the tube, and the newer furnaces have center kiln sections with walls 3-1/4" thick. After explosion or burning, the items progress on through the 1200OF section and fall out the discharge end onto another conveyor which carries the now-inert metal parts to a scrap collection bin. Some installations carry the scrap metal over a magnet which separates ferrous from non-ferrous scrap, and others simply collect mixed scrap. Some installations collect molten lead in ingot molds, and others simply leave it in the mixed scrap.

c. The quantity of detonating explosives allowed to be fed to the Deactivation Furnace is normally limited to 600 grains (0.0857 pounds, or 38.9 grams) per item; which permits the handling of intact small arms ammo through 20-mm and most artillery fuzes, primers and the like. Typical feed rates run about one item per second.

d. The probable ultimate safety limit is much larger than 600 grains. A special APE-1236 unit at Rocky Mountain Arsenal regularly contained the combustion of 0.55 pounds of tetryl in M-34 bomblets without mishap; up to 600 lb/hr of flaked TNT has been successfully burned at Tooele Army Depot in experimental runs; and Edwards AFB has successfully burned five to ten-pound chunks of rocket propellant in bags. Tooele has also successfully burned approximately five-pound chunks of TNT cast in cans or steel rings. Note, however, that these large burnings have all been deflagrations and not detonations. The TNT was either flaked or carefully presented with large, unconfined surfaces; rocket propellants inherently burn instead of detonating unless boosted by a high-order initiating charge; and the M-34 bursters had been punch-sheared to open them before being fed to the furnace. The official limit for APE-1236's in the field is still 600 grains per flight.

e. The fuel oil consumption of the APE-1236 is estimated by Tooele AD at 9 to 21 gallons per hour, depending upon the work rate.

f. The APE-1236 Deactivation Furnace is described in detail in the Army "Operation and Maintenance Manual, Deactivation Furnace APE 1236," 9 December 1970, U. S. Army Munitions Command, Dover, New Jersey (83); and the APE 1276 Air Pollution Control System is described in a Test Report, "APE-1276 Pilot Model Air Pollution Control System for APE-1236 Deactivation Furnace," by Daniel B. Hill, Ammunition Equipment Office, Tooele Army Depot, Tooele, Utah 84074, July 1976, Report AEO-052-76 (32).

9. OPEN BURNING GROUNDS

a. Other than the now-banned ocean dumping, open burning is perhaps the oldest and most universal demilitarization technique. One simply piles the unwanted material in a remote, open field with sufficient starter fuel such as excelsior, wastepaper, scrap dunnage, etc., and ignites it. There is no elaborate equipment, negligible fuel cost and little labor cost. However, it is sometimes a very smoky operation, and it is no longer ecologically acceptable in some states when there is any alternative. However, there may be no alternative at times, as in the case of white phosphorus shells, certain surplus rocket motors and items too deteriorated for safe disassembly. Therefore, open burning is universally practiced to some degree, and will probably always be necessary to a limited extent.

b. Three examples will illustrate typical events at an open burning ground. The first example is an open-burn of several hundred pounds of cannon powder which was witnessed at an Army Depot. The powder was poured out on the ground and ignited remotely with an electric igniter. It made a great, roaring bonfire a hundred feet or so high, with much heat and light but very little smoke or visible NO_x . After the cannon powder bonfire died down, smaller fires of other materials being destroyed continued to burn with about as much smoke as that from a grass fire.

c. The second example is the firing of surplus, intact, Falcon rocket motors and nozzleless Hawk rocket motors. All were buried in the ground, nose down with the nozzle ends sticking out vertically, and ignited remotely. The Falcon motors gave a brief but intense blast of flame and smoke jetting vertically upwards for approximately two seconds each. There was a visible cloud of NO_x from the combustion of the double-base propellant, but it vanished in a few seconds. The considerably larger, two-stage Hawk motors burned much more slowly and in two distinct stages: an initial high-intensity burn of an aluminized booster grain, followed by a much slower burn of a double-base sustainer grain. There was a visible cloud of aluminum oxide smoke from the booster grain but only small amounts of visible NO_x from the sustainer grain. Occasionally, a burning grain would suffer partial breakup in the motor; and a chunk of burning propellant would be thrown into the air to fall back and finish burning on the ground. After these burns, the air was clear, and there was no residual pall of smoke.

d. The third, and most typical, example is the open burn of 300 105mm, Comp B-filled projectiles at another Army Depot. The projectiles' fuzes and booster wells had been removed to expose the fill. The projectiles were laid out on their sides in long rows on the ground, and excelsior and scrap wooden boxes were piled around the open noses for kindling. The kindling was ignited remotely, and the Comp B melted and burned quietly in the heat of the wood fire. The fires were small, and there was only a little visible smoke - about as much as would have been expected from the wood fires alone. Total explosive content was ~600 kg.

10. DETONATION GROUNDS

a. High-order detonation is also an old and universal disposal method, and it is sometimes the only available method when an item such as a large bomb or shell is so deteriorated or so constructed that there is no safe way to disassemble it. Like open burning, a limited amount of detonation will always be necessary, and every depot remote enough to have the necessary isolation has a detonation ground. The following examples of detonation operations are typical.

b. One detonation ground is a 4000-acre stretch of desert in the West approximately eight miles northeast of the depot which is itself ten or more miles from the nearest civilian town. The detonation ground has 14 pits - wide, shallow depressions - for disposal of ammunition items by detonation; and up to 10,000 pounds of HE* can be detonated in each pit. The detonation of a stack of 30 280mm shells containing a total of 3,000 pounds of TNT was witnessed from a distance of approximately one mile. At that distance, it made a flash and a pop, and threw up a cloud of sand and dust which soon settled back onto the desert floor. There must have been NO_x and carbon particles in the cloud - and there would have been more from some other explosives such as Comp B - but the visible color of the cloud matched that of the desert floor, and there was no lingering color or haze in the air afterward. There is no water at this site. Scrap metal was recovered from the desert floor with truck-mounted magnets.

c. A quite different detonation ground is one in the Eastern part of the U. S. There, detonations are carried out underground, in holes bored in the earth with a truck-mounted earth auger. The observed shot was of 160 pounds of mixed items at the bottom of a bored hole along with a suitable booster and detonator cap ensemble. The remainder of the hole had been filled with earth (so that the charge was at least five feet below the original

* High Explosive

surface); and a 5-foot mound of earth had been piled on top of that by bulldozer, so that the explosive charge was buried at least ten feet deep with earth. Detonation of the charge resulted in a plume of earth like that from an excavation blast and a heavy "thud" with no sharp "crack". There was a considerable cloud of dust and earth - again like that from an excavation blast. The dust obscured any NO_x and unburned carbon that might have otherwise been visible. There was a crater approximately five feet deep and eight feet wide from each shot. Subsequently, the earth was smoothed down with a bulldozer; and the site was used again for more demolitions. There was no scrap metal to be collected on the surface.

d. Only one depot buries its detonations in bored holes, but a number of them mound four to ten feet of earth over the charges; and they achieve proportionate muffling of the sound and blast effects. Safety limits range from 500 to 10,000 pounds of high explosive per shot, depending mostly upon the remoteness of the site.

SECTION II

PROCESSES IN LOCAL USE

11. INTRODUCTION

In addition to the standard demilitarization processes described above, there are several processes which are in routine use at one or two bases but have not been widely adopted as yet. Four examples will encompass the most significant of these operations.

12. STEAMOUT OF EXPLOSIVE FILLS

a. Steamout is similar to hot water washout in that both processes essentially melt out TNT fills from large-caliber projectiles, bombs and other munitions. There are two important differences: steamout is pretty well limited to TNT-only fills, since it lacks the erosive action of the pressurized jetting hot water, but steamout also gives less water to dispose of eventually than washout.

b. The steamout process is well exemplified by the facility at NWSC Crane. This facility handles large items such as 250 to 1000 pound bombs, mines, depth charges and torpedo warheads; and

also smaller items such as 5-inch and 120mm shells. The large items are placed on an inclined cradle, and 5 to 15 psi steam is jetted in to melt out the fill. Two lances are used, the first with an axial jet and a second with side jets. The molten slurry is collected in a jacketed pipe header with rubber connectors and flows to an agitated kettle and thence to corrugated cooling pans. The pans are held in a vented and heated hood until the water is all evaporated, and are then cooled to allow the explosive to solidify. The solidified explosive is broken up into chunks, boxed and shipped out. The empty metal case is steamed again on a vertical cradle to remove any remaining explosive as well as the asphalt liner if there is one, and the cleaned case then goes to metal reclamation. The sludge from this final steaming is burned.

c. This facility also has a number of steam cabinets for 5-inch and smaller items. These items are simply stood vertically, open end down, on racks in the cabinet, and surrounded with steam until the explosive melts and runs out. There are no jets into the munitions.

d. There is no gross water discharge from this facility. Most of the steam condensate evaporates from the corrugated pans, and the discharge is mostly washdown. There is a major problem in that much TNT steam-distills overhead with the evaporated water and deposits in the overhead ductwork, from which it must be manually cleaned periodically.

e. The explosives removal mechanism relies primarily upon the melting action of the hot steam, and there is little or no erosive action. Consequently, the process is best for TNT-only and less effective for fills with a high percentage of non-meltable components such as RDX, HMX or aluminum. By the same token, the process is superior for TNT because the steam vapor expands to fill even the most irregular cavity and gives better heat transfer than hot water, which must impinge directly onto the explosive in order to melt it. It has another advantage in that the only wastewater is steam condensate, and that is evaporated in the dewatering step, so that there is minimal wastewater disposal problem. However, this is a time-consuming, manual process.

f. It should also be noted that, in spite of the feeling that steamout is effectively limited to TNT fills, NWSC Crane has successfully applied it to H-6, Tritonal and HBX. Nevertheless, a study done by Battelle for the Western Demilitarization Facility (121) recommended that it be considered mainly for TNT-only fills.

g. Although it cannot be considered a widely used process, there are steamout facilities at NAD Hawthorne, NAD McAlester, NWS Yorktown, NTS Keyport, Joliet AAP, Cornhusker AAP, Newport AAP and Pine Bluff Arsenal (for white phosphorus). There is also a related "meltout" process installed at Ravenna AAP for removing TNT and Comp B loads from 90mm and 155mm projectiles. This Meltout Process applies steam to the outside of a munition in a steam cabinet, and does not inject it into the interior.

13. DRILLOUT OF EXPLOSIVE FILLS

a. This operation - also known as contour drilling - is essentially a lathe drilling operation. De-fuzed projectiles are mounted in a slightly modified metal lathe and rotated at about 150 rpm while a stationary, non-sparking bit advances into the cavity, milling out the fill as a powder, which is collected by a vacuum hose for conveying to a collector in an adjacent building. A cam tilts the bit to follow the contour of the projectile interior so as to leave about 1/4 inch of the fill untouched. The 1/4 inch is a safety allowance; the bit could follow closer than that. A lathe can do about a shell a minute, and TNT, Comp A-3, Comp B and Ammonium Picrate have all been successfully drilled out. The product is a dry powder, ready for shipment; but the projectiles need further cleaning since they still contain a layer of explosive fill.

b. The drillout machines are not standard APE items. Prototypes exist at NWSC Crane and NAD Hawthorne, and they appear to have been developed locally.

14. HIGH PRESSURE WASHOUT OF EXPLOSIVE AND PROPELLANT FILLS

a. High-pressure water washout - also called "Hogout" - is not widely used; but there are at least two operational facilities, and there are others either in layaway or under reconstruction. The technique has been applied more to the removal of propellant from large rocket motors than to the removal of explosive fills from projectiles, but the most illustrative example seen on this project was a new one at NWSC Crane for the removal of HE from 3-inch to 6-inch projectiles.

b. In the Crane process, a defused 5-inch (for example) projectile is clamped into an approximately horizontal cradle; and a water lance penetrates into the cavity as the fill is washed out by a 9000 psi axial water jet. Afterwards, the partially washed-out projectile is moved to a second station identical to

the first except that the lance has two lateral jets instead of an axial jet; this washes out the fill adhering to the sides of the projectile. At both stations, the projectile is rotated during washing.

c. The drained water goes through a hydrosieve and a clarifier, then to a clearwell for recycle back to the pump. The ejected, granular, explosive/water slurry is collected in a flume and poured into lined boxes. It is sold drained but "wet" (about 15% water) without further processing for commercial purposes. The empty cases are clean without further treatment, and they go to metal reclamation.

d. Another hogout facility is operated at NOS Indian Head at ~5000 psi for the removal of propellant from rocket and missile motors.

15. DEMILITARIZATION OF MAGNESIUM FLARES

a. In the past, unserviceable magnesium flares have generally been demilitarized by open burning; but a successful pilot line for chemical demilitarization has been demonstrated at NWSC Crane, and the process is being installed at Longhorn AAP.

b. Mk 24 and Mk 45 aircraft parachute flare candles are mechanically removed from their containing tubes and then crushed submerged in a bath of "STRIPOXY" solvent, a commercial solvent which softens and disintegrates both the laminac and the epoxy binders used in the flare candles. The candle pieces and the solvent are fed into a mixing tank and stirred until the crushed pieces of candle are thoroughly disintegrated. The solvent and dissolved binder are decanted from the settled magnesium powder and sodium nitrate oxidizer, and the spent solvent is sent back to the manufacturer for reclamation. The granular residue of magnesium and sodium nitrate is washed with acetone, isopropyl alcohol and/or water to dissolve the sodium nitrate and any remaining binder and leave relatively clean magnesium powder as one product of the process. The magnesium is suitable for re-use in decoy flares. The sodium nitrate is also recovered in a subsequent evaporation step and is being evaluated at this writing for use as fertilizer.

SECTION III

PROCESSES UNDER DEVELOPMENT

16. INTRODUCTION

The following demilitarization processes are currently in

various stages of research and development, and at least some of them may become standard demilitarization processes in the next few years.

17. FLUID BED BULK PEP* INCINERATOR

a. This process, under development by and at Picatinny Arsenal, is an adaptation of commercial fluid bed incinerators. The pilot unit consists of a fire-brick-lined vertical cylinder 8 feet in diameter and filled to a depth of 4 feet (static) with granular alumina. The alumina is fluidized (the expanded bed depth is 8 feet) with air injected through a manifold grid at the bottom of the bed; and it is brought up to operating temperature with fuel oil which is injected into the fluidized bed through a ring of spray nozzles near the bottom of the bed and burned inside the bed with the fluidizing air. While the bed is heating, the PEP to be incinerated is shredded and/or granulated under water to make a pumpable slurry of about 25 Wt-% PEP; the slurry is then held in a stirred feed tank near the incinerator building. When the bed is hot, the PEP slurry is injected into the bed through another ring of injector nozzles, and it burns with nearly enough heat of combustion to evaporate the water and maintain the bed temperature without the use of supplementary fuel oil. Thus, once started, the incineration is self-sustaining.

b. NO_x emission are expected to be low due to the use of an NO_x -decomposition catalyst (nickel) and staged combustion. The bed is fluidized with less than the stoichiometric amount of air so that the PEP burns in under-oxidized conditions and yields a combustion gas which is still fuel-rich (i.e., reducing) and high in NO_x . Under such reducing conditions and in the presence of the catalyst, NO_x is reduced to elemental nitrogen. Additional air is then injected high up in the bed - above the NO_x reduction zone - and the remaining fuel value of the gases is burned to stoichiometric at a temperature low enough that very little new NO_x is formed. The best demonstration run to date emitted 15 ppm NO_x (and <1 ppm hydrocarbons and too little CO to measure) at a PEP feed rate of 177 pounds/hour.

c. The pilot incinerator has an exit gas cyclone to catch attrited alumina and any particulates from the burned PEP's. The need for stack gas scrubber has not been determined.

d. However, other reports (35a) indicate relatively high capital and operating costs and energy consumption for the fluid bed incinerator.

*Propellant, Explosive and Pyrotechnic

e. At this writing, demonstration tests are continuing at Picatinny, and a definitive report including verified performance and cost data will be forthcoming. Preliminary data and an evaluation are given in Chapter III.

18. ROTARY KILN BULK PEP INCINERATOR

a. This process is under development at Radford AAP under Picatinny Arsenal sponsorship. It has been demonstrated on a 250 pounds per hour scale, and two full size units (550 pounds per hour) are under construction.

b. The rotary kiln is a horizontal rotary furnace not unlike the APE-1236 Deactivation Furnace described in paragraph 8, except that it is lined with fire brick and has no internal flights. It is inclined slightly toward the discharge end so that the ash slowly moves toward the cleanout door located underneath the burner.

c. PEP to be incinerated is shredded to less than 0.1 inch in diameter, suspended in water in a manner similar to that in the fluid bed feed unit above, and injected into the hot (about 1600°F) kiln through a single pipe. The slurry is spread out into a thin film by the rotating wall, and it first evaporates and then burns as it moves along. The exhaust gases go through an oil-fired afterburner to burn CO and hydrocarbons, and then through a pre-cooler and a marble bed wet scrubber.

d. This incinerator, like the fluid bed incinerator, is nearly self-sustaining from the heat of combustion of the PEP; and its NO_x emission level has been running somewhat under 200 ppm. It is still under evaluation, and a definitive report, including cost comparisons, will be forthcoming. Capital and operating costs as well as energy consumption are expected to be high (35a).

19. BULK PEP'S IN THE APE-1236 DEACTIVATION FURNACE

a. This subject was introduced above in paragraph 8. The basic concept is that multi-pound chunks of bulk explosive or a continuous stream of shredded explosive can safely be burned in the Deactivation Furnace provided it only burns and does not detonate. Tooele AD has a standard APE-1236 Deactivation Furnace in which coffee-can-sized containers of bulk TNT have been burned in large numbers without incident, and it is reported that Edwards AFB regularly burns 5 to 10-pound chunks of rocket propellant in bags in their deactivation furnace. No shredding or slurring water

is used in either operation; care is taken to ensure that the PEP has a maximum of exposed surface on which to ignite and burn, and that there is no confinement to accelerate the burning to detonation. Another, similar deactivation furnace has been used to burn intact M25A2 CS grenades, burster and all. It should be noted that the burning of large chunks of explosives in the deactivation furnace should be - and is being - approached with extreme care. No mishaps have been encountered in burning bulk materials to date, but the operation has not yet been approved for anywhere other than the experimental site at Tooele AD.

b. Tooele has very recently installed a new bulk PEP feed system featuring a chain belt conveyor and a ram to shove the charges deep into the hot furnace without hesitating at the mouth. It is too new to have developed any operating experience at this writing.

c. The burning of bulk quantities of PEP's in the APE-1236 will present all the same emission problems as the burning of small items, except that the concentrations of NO_x , particulates and other constituents will be higher due to the higher mass feed rates, and more elaborate gas cleaning facilities may be required.

20. CAVITATING WATER JET (CAVIJET™) WASHOUT

A cavitating water jet (CAVIJET™) system was successfully tested at the "Hogout" facility at NOS Indian Head on Tartar Motors. Propellant was removed at one half the normal Hogout pressure and in one third less time. A new Hogout facility is planned for installation at Indian Head, although details are not available at this writing.

21. WET AIR OXIDATION

a. Wet air oxidation is an adaptation of a commercial process for the under-water "combustion" of concentrated aqueous organic wastes such as sewage sludges and some industrial waste streams. At NOS Indian Head the waste is injected into a water-filled pressure reactor at 150 to 2,000 psi and about 200°C along with sufficient high pressure air to effect the oxidation of the waste. Oxidation proceeds in the reactor with (typically) the evolution of enough heat to sustain the temperature, and the exit stream is used to pre-heat the incoming stream via a heat exchanger.

b. The cooled exit stream is separated into gaseous and liquid phases, and the gas phase is treated by an afterburner to destroy

CO and residual hydrocarbons followed by a wet scrubber to remove NO_2 before discharge to the atmosphere. The liquid stream, which typically contains a few percent nitric acid, is neutralized with ammonia to produce ammonium nitrate and to precipitate out metal salts as hydroxides. The metal hydroxides would go to a recovery or disposal operation, and the liquid phase would be concentrated by reverse osmosis or other treatment to recover ammonium nitrate and send the purified water back to the feed preparation stage.

c. As in the fluid bed and rotary kiln incinerators described above, bulk PEP's are shredded or granulated to small dimensions and slurried in water, primarily so they can be handled in the high pressure pumps and pass through the various pipes and valves. An evaluation is given in Chapter III.

22. CLOSED PIT INCINERATOR

This incineration process, demonstrated on a batch scale at the Pantex AEC Plant by Mason and Hanger, consists essentially of open burning inside a closed room. Typically, several hundred pounds of waste bulk explosives or propellants are stacked on the floor inside a modified explosives storage igloo and ignited. A 20,000 cfm air blower outside pumps in more than enough air for stoichiometric combustion, and the combustion gases and excess air exit through the roof which has been modified to be a several-foot-thick sand bed supported on a suitable truss and screen ceiling. It is reported that all smoke and particulates are retained by the sand filter, but there are not yet definitive data on NO_x and other gaseous emissions, or on how often the sand filter has to be changed.

23. BATCH BOX INCINERATOR

This unit has been developed by NAPEC, Crane, and a prototype has been installed at NAD McAlester. It is basically an oil-fired trash incinerator with overfire air, adapted for handling small PEP items and PEP-contaminated dunnage. Dunnage is charged batch-wise through side doors, and small PEP items are fed into the flame via a steep entry chute. Exhaust gases go through an afterburner and a marble bed wet scrubber prior to venting through the stack. The prototype is still undergoing evaluation, and a definitive report is not yet available.

24. PHOSPHORUS SMOKE COMPOSITION INCINERATOR

At this writing, this is a laboratory bench-top program, directed at a process for the ecological destruction of some half a million pounds of smoke composition containing red phosphorus/pyrolusite/ MgO /linseed oil. Burning it is no problem, but collecting the P_2O_5 smoke is a problem. The plan is to burn 10-pound batches in a two-chamber furnace at 1200-1600°F to P_2O_5 , absorb the P_2O_5 in water and sell fertilizer grade H_3PO_4 . At the time of this study, a 1/10-scale pilot plant had been built, and one run had been made. There were not yet any data.

25. MICROWAVE MELTOUT

a. This is a highly experimental process under study at Tooele AD. In it, a beam of microwave energy is directed onto the explosive fill (for example TNT). The explosive preferentially absorbs the energy, melts and runs out as a liquid, leaving the munition wall and liner intact and cool. There is no water, no contamination and no polluting effluents. The recovered explosive is molten and ready for re-use. The energy consumption is expected to be small compared to hot water washout.

b. The process is in the very early stages of development and is not yet ready for large scale application or even scale-up. Safe energy fluxes and control conditions still have to be established, and there has been one runaway event. Nevertheless, the promise of low energy consumption, clean explosive recovery and no effluents make this process well worth further attention.

26. LEAD AZIDE ELECTROLYSIS

Lead azide is a particular nuisance to demilitarize by incineration or open burning because it always detonates and it yields finely-divided metallic lead as a combustion smoke. Electrolysis in a strong caustic medium is being piloted at Iowa AAP with good initial success and the recovery of high-purity massive lead in electrode ingot form. At this writing, no report is available on any gaseous emissions from the electrolysis or on any disposal problems with the spent electrolyte.

27. SOLVENT BREAKDOWN

This is a Navy effort, and mainly in the test tube stage, although the magnesium flare process described in paragraph 15 is a large-scale example. The concept is to chemically disassemble

composite explosives and propellants - particularly plastic-bonded explosives - by dissolving or chemically degrading the binder and releasing the dispersed metal powders and granular oxidizers for recovery and re-use. A discussion is beyond the scope of this Phase I study except to note that the concept offers a large degree of ingredient recovery, elimination of gaseous effluents, but a whole new set of problems in solvent recovery and sludge disposal.

28. BIODEGRADATION

There are a dozen or so research projects underway in the Army and in the Navy to try to destroy waste explosives - particularly dilute wastes - by biological action similar to that used in municipal sewage treatment plants or composting operations. They are mainly directed at TNT, RDX and NG wastes. There are formidable problems involved. The explosive materials tend to be refractory and toxic to microorganisms, and they require large amounts of supplementary nutrients. Moreover, they tend to degrade only one molecular step or two and to yield partial degradation products which are both more refractory and more toxic than the original explosives were. A useful summary of the biodegradation research in progress would be a major study of its own and is beyond the scope of this report, except to note the existence of the program. This process was evaluated in the previous ADPA Study (2).

29. AIR CURTAIN INCINERATOR

a. The air curtain incinerator is a device one step more sophisticated than open burning. In its original embodiment, brush from land clearing operations was burned in an open pit while a curtain of air was blown over the top of the pit and down into the far side of it from an air blower on the ground above. The excess air served to achieve complete combustion of the carbon in the smoke and to reduce or eliminate visible emissions.

b. In the prototype demilitarization air curtain incinerator at Radford AAP, the fire pit is a room-sized box lined with firebrick and built at the end of a truck ramp. The top is largely open, and a curtain of air is blown over the top and down into the box by a large, external air blower. There is a screen enclosure as large as the firebox itself on top of the unit. The charge, mostly contaminated dunnage, is loaded into the cool firebox, ignited and burned with the blower running. It is reported that visible emissions are low. Sixteen of them are planned for installation at AAP's and Depots.

SECTION IV

CURRENT DEMILITARIZATION FACILITIES

30. INTRODUCTION

The overwhelming majority of the demilitarization operations in the U. S. are carried out at Army Depots or Navy Facilities where the munitions are stored. A relatively minor amount - disposal of reject products and manufacturing wastes - is done at AAP's; but it does not differ significantly from that done at the Depots, and it will not be discussed here. There are some 38 locations in the U. S. which have a demilitarization capability. Their locations are shown in Figure 6.

31. DEPOTS AND THEIR DEMILITARIZATION CAPABILITIES

a. Demilitarization operations at the Army Depots are just as standardized as the Army can make them, for the sake of uniformity of results and safety. They generally have the same equipment - except when a Depot does not have a particular item at all - and the equipment is operated according to the same procedures and SOP's. Post-to-post variations are so minor as not to warrant mention here at all. The demilitarization facilities of each Depot* are summarized as follows:

ACTIVITY	DEACTIVATION			
	<u>FURNACE</u>	<u>WASHOUT</u>	<u>DETONATION</u>	<u>OPEN BURN</u>
Anniston AD	X	X	X	X
Letterkenny AD	X	X	X	X
Lexington- Bluegrass AD	X	X	X	X
Pueblo AD	X	X	X	X
Navajo AD	X	X	X	X
Ft. Wingate AD	X	X	X	X
Red River AD	X	X	X	X
Seneca AD	X		X	X
Sierra AD	X		X	X
Tooele AD	X	X	X	X
Umatilla AD	X	X	X	X
Savanna AD	X	X	X	X

b. Operations at the NAD's are a little more varied than the ones at the Army Depots, because experimental work is a little more decentralized in the Navy; but the operations are still

*With the exception of washout, all demilitarization operations were in periodic use at the Depots indicated in 1976.

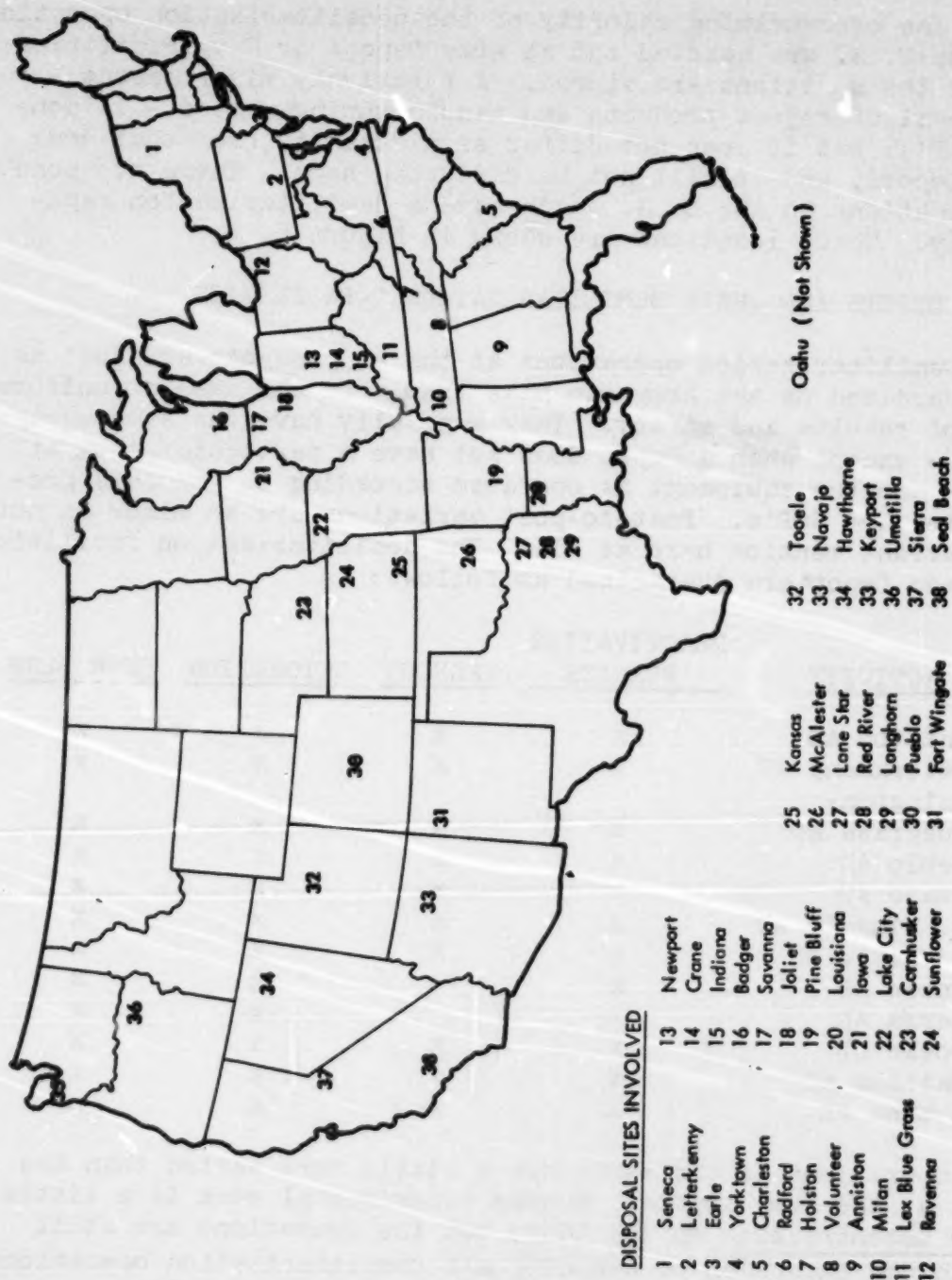


Figure 6 - Demilitarization Locations

similar enough to lend themselves to the same categorization used above:

<u>ACTIVITY</u>	<u>DEACTIVATION</u>			
	<u>FURNACE</u>	<u>WASHOUT</u>	<u>DETONATION</u>	<u>OPEN BURN</u>
NWSC Crane	X	X	X	X
NAD Hawthorne	X	X	X	X
NAD McAlester	X	X		X
NAD Earle	X	X		X
NWS Yorktown		X	X	X
NWS Seal Beach			X	X
NWS Charleston	X		X	X
NTS Keyport	X	X		X
NOS Indian Head		X		

c. As mentioned, the AAP's demilitarization operations are minor; but they do exist, and they are summarized on the following chart:

<u>ACTIVITY</u>	<u>DEACTIVATION</u>			
	<u>FURNACE</u>	<u>WASHOUT</u>	<u>DETONATION</u>	<u>OPEN BURN</u>
Iowa AAP	X	X	X	X
Ravenna AAP	X	X		X
Joliet AAP	X	X		X
Cornhusker AAP		X		X
Newport AAP	X	X		X
Longhorn AAP	X		X	X
Pine Bluff Arsenal	X	X	X	X
Milan AAP		X	X	X
Kansas AAP	X		X	X
Lone Star AAP	X		X	X
Volunteer AAP				X
Sunflower AAP				X
Holston AAP				X
Radford AAP	X			X
Indiana AAP				X

32. PLANNED EXPANSIONS

There are no major planned expansions of current facilities, since the demilitarization workload is currently diminishing and many of the present facilities, particularly washout plants, are in layaway; but there are a number of minor upgrading projects in progress, mostly to meet more stringent environmental

requirements. Every Army deactivation furnace, for example, is in the process of receiving an emissions control system in the form of a cyclone and a baghouse to remove particulates from the stack gasses. Most of the washout plants are scheduled to receive improved water cleanup systems in the form of charcoal filters, and 16 locations are planned to receive air curtain incinerators to cut down on the demands for smoky open burning. There are two major new facilities planned, and they are discussed in the next section.

SECTION V

PLANNED NEW DEMILITARIZATION FACILITIES

33. INTRODUCTION

There are currently two brand-new demilitarization facilities planned in the U. S., a major facility at NAD Hawthorne, and a pilot facility at Red River AD.

a. Western Demilitarization Facility

A major, new demilitarization facility known as the "Western Demilitarization Facility" is under construction at NAD Hawthorne, Hawthorne, Nevada (1). It is intended to demilitarize the full range of DCO conventional munition commodities, from small arms ammunition to large underwater mines, as well as bombs and major and intermediate caliber projectiles, without open burning or detonation, and to incorporate all the best features of current operational and experimental facilities.

It is to be a multi-building complex, sited as shown in Figure 7, and including:

- o Off-loading dock
- o Preparation building
- o Smokeless powder accumulation
- o Process storage magazines
- o Mechanical removal complex
- o Washout/steamout complex
- o Meltout and refining building
- o Bulk explosive disposal building
- o Decontamination furnace
- o Boiler plant and service building

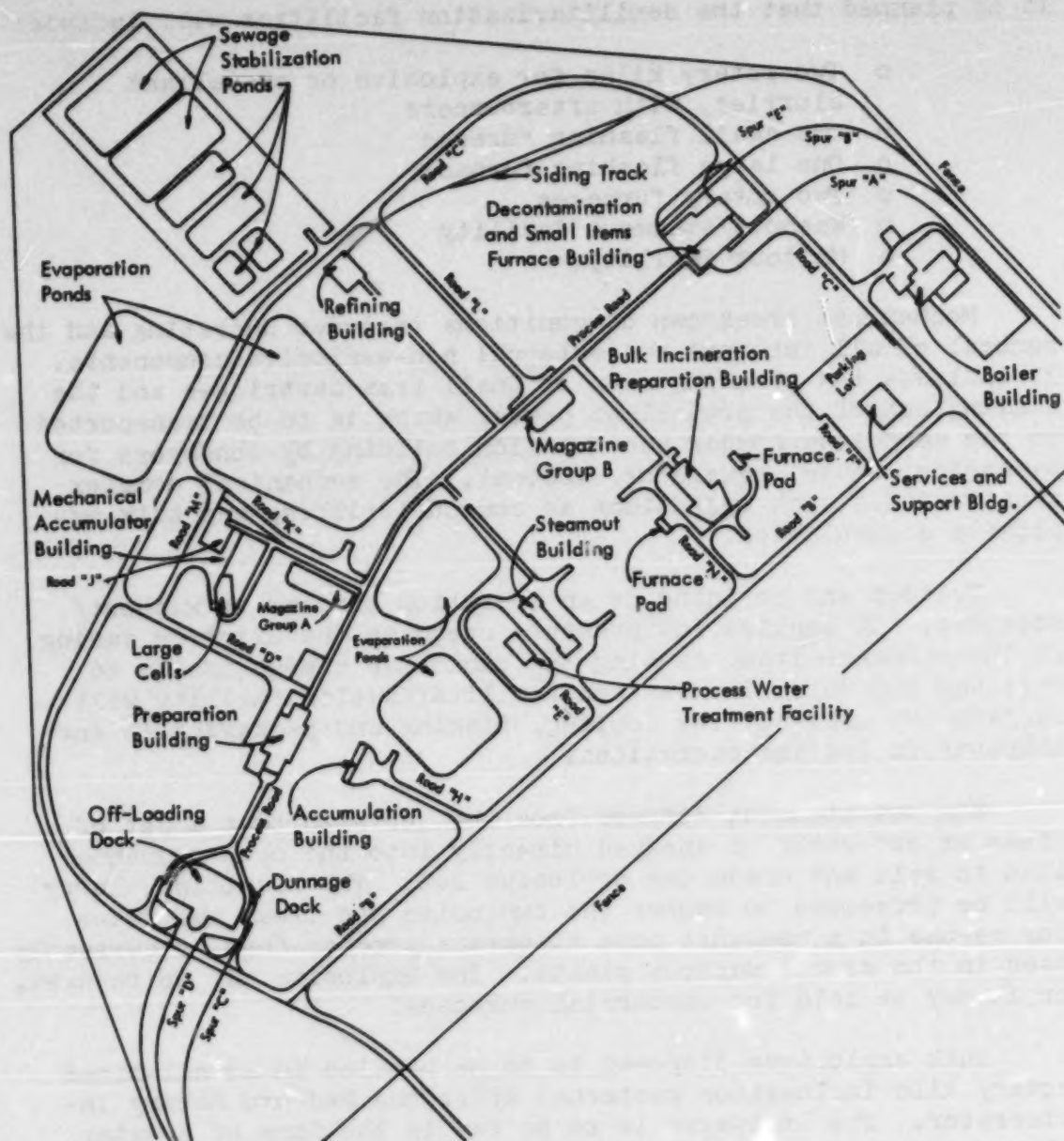


Figure 7 - Western Demilitarization Facility, Naval Ammunition Depot, Hawthorne, Nevada (1)

It is planned that the demilitarization facilities will include:

- o Two rotary kilns for explosive or propellant slurries, with afterburners
- o One small flashing furnace
- o One large flashing furnace
- o Two rotary furnaces
- o Washout/steamout facility
- o Meltout facility.

Mechanical breakdown of munitions includes uncrating and the removal of all internal and external non-explosive components. It includes the breaking open of small arms cartridges and the shaking out of the propellant powder which is to be transported to the smokeless powder accumulation building by conveyors for packaging, reuse, resale or disposal. The mechanical complex also includes such operations as contour drilling and bulk explosive accumulation.

Meltout and refining is an operation similar to washout/steamout. It applies low pressure steam to the exterior casing of the ordnance item, causing the explosive charge inside to melt and run out. The Western Demilitarization Facility will reclaim the explosive by cooling, flaking and packaging it for shipment to loading operations.

Washout/steamout differs from the above in that a jet of steam or hot water is sprayed directly into the open ordnance item to melt and erode the explosive out. The resulting slurry will be processed to remove the explosive and treat the water for re-use in a somewhat more elaborate process than is currently used in the Army's washout plants. The explosive may be re-used, or it may be sold for commercial purposes.

Bulk explosives disposal is to be handled in an oil-fired rotary kiln incinerator patterned after the Radford Rotary Incinerator. The explosive is to be fed in the form of a water slurry of not more than 25% explosive content for safety. The incinerator stack will have an afterburner to consume any fuel-rich pyrolysis gases.

Decontamination furnaces will include APE-1236 popping furnaces of standard Toeole design for small arms ammunition, fuzes and other small items, and larger flashing furnaces or chambers for burning off residual explosives from larger ordnance items. All processes are to be enclosed, but the treatment of

combustion products prior to release to the atmosphere has not yet been fully decided.

Service facilities include control rooms, magazines, a boiler plant and a water treatment plant, as well as a laboratory, locker rooms, lunchroom, etc.

b. DARCOM Ammunition Center Depot Disposal System

In an attempt to meet the twin challenges of disposing of all waste materials generated by depots' operations and doing so in an environmentally acceptable manner, the Army is contemplating the construction of a new, modular, pilot demilitarization facility, probably at Red River AD (80).

The facility is to consist of three basic operational units - a fluidized bed incinerator, a confined detonation unit and a decontamination oven - each of which is multi-purpose and complements the others in operation. All are to be connected to a single exhaust gas treatment section.

The fluidized bed incinerator will accomplish disposal of all combustible material, including explosives, dunnage and trash. A fluidized bed features good temperature control and heat sinking, the opportunity for NO_x control by catalytic reduction and staged combustion, inherent barricading, and the ability to accept both shredded dunnage and paper wastes, and water slurries of shredded or granulated explosives. It can be operated to be self-sustaining as to fuel requirements and to give very low emissions levels.

The confined detonation chamber is a reinforced concrete blast containment structure for detonation of explosives in quantities up to 100 pounds and for burning of pyrotechnics in munitions which cannot be opened or for which disassembly is uneconomical and whose explosives charges exceed the limits of the deactivation furnace. The chamber attenuates noise, contains explosive particulates, and allows gaseous emissions to be directed through gas cleaning equipment prior to release to the atmosphere. The chamber can be exhausted in 3 to 10 minutes, thus allowing a relatively short cycle time between detonations.

The decontamination chamber is essentially an oven positioned in the exhaust gas line from the fluidized bed incinerator. The 1000°F to 1400°F gases will pass through and pyrolyze any remaining explosives adhering to the metal parts, washed-out projectile

cases, etc., placed therein for flashing. The exit gases will pass directly to the gas cleaning unit or back to the fluidized bed if afterburning is indicated.

Air pollution control equipment will consist of venturi collectors for particulates down to 0.1 micron, and packed tower scrubbers for dust and gas absorption.

This new facility is in the concept design stage. No specifications for combustion equipment or pollution control equipment have yet been written, and no site plan has been drawn up. Funds have not yet been committed. Even when built, this facility is not intended to be a major, production demilitarization facility like the Western Demilitarization Facility; rather, it is intended to be a prototype facility for development of improved modules for installation at appropriate Army Depots.

SECTION VI

SPECIAL DEMILITARIZATION FACILITIES

34. INTRODUCTION

Although technically beyond the scope of this study, it is useful to describe two chemical agent demilitarization facilities for the insights they provide into just how much can be done in the way of advanced technology for demilitarization and emissions control.

a. Rocky Mountain Arsenal (RMA) Demilitarization Operations

Lethal chemical munitions containing Agents GB and Mustard have been demilitarized in special facilities at RMA over the past several years with what amounts to zero discharge of toxic gases. Major demilitarization projects have included the Honest John warhead, the M34 GB cluster and bulk Mustard in one-ton containers (118).

(1) The Honest John warhead is a rocket nose cone 115 inches long, 30 inches in diameter and containing 368 spherical, GB-filled bomblets about the size of a grapefruit. Each bomblet contains 1.1 pounds of GB and 0.16 pound of Comp B burster.

The bomblets are manually downloaded onto a conveyor equipped with fixtures which position them firmly for the punch, drain

and rinse operations which follow. The conveyor carries the bomblets into an 8,000 square foot explosion and chemical containment cubicle whose walls and ceiling are one-foot-thick concrete lined with welded, one-quarter-inch steel plate. The cubicle is fitted with observation windows composed of two plates of Lexan 1-5/16-inch thick separated by a two-inch air space. Inside the containment cubicle, the bomblets are remotely punched and drained of GB, water rinsed and probed, and water rinsed a second time.

The GB, along with the water rinses, is piped to a storage tank and hydrolyzed with caustic to destroy the GB. The resulting brine, consisting mainly of sodium fluoride and sodium diisopropylmethylphosphonate, is spray dried in a centrifugal atomizing chamber at 30 gpm, and the dry salts are stored in 55-gallon drums.

The empty bomblets are conveyed to the furnace room and manually loaded into a standard APE-1236 deactivation furnace where the bursters are pyrolyzed at 500°F, adequate for the pyrolysis of Comp B but well below the melting point of aluminum. The burned bomblet shells are then conveyed to a second, decontamination furnace where the aluminum shells are melted at 1500°F and cast into ingots.

The entire Honest John facility is operated under negative air pressure, and all plant air and furnace gases are collected in a series of ventilation ducts for post-treatment consisting of quench, nine separate packed column caustic scrubbers with a total capacity of 260,000 cfm, a venturi scrubber and a tall stack. GB removal efficiency is 99.9997%.

(2) An M34 cluster contains 76 cylindrical bomblets about a foot long and four inches in diameter. Each one contains approximately 2.6 pounds of GB and half a pound of tetryl, for a total of 42 pounds of tetryl and 200 pounds of GB per cluster.

Except for initial preparation for disassembly, all M34 demilitarization operations are performed remotely by automatic machines in containment bays similar to the Honest John cubicle described above, except that the M34 chambers could contain the detonation of fifty pounds of TNT without rupture. In the first step, the outer case is pulled from the cluster, the steel bands and the metal bars which hold the bomblets in place are removed, and the bomblets are transferred one at a time to a box where the fuze arming rim is staked by a hydraulic ram. The bomblet

then moves to the next station where it is punched and drained of GB.

The bomblet is weighed to verify that it has been drained, passed through a caustic rinse and moved to a machine which shears the burster. It is then conveyed to another APE-1236 deactivation furnace where the burster is burned, and finally through a 30-foot-long, 1500°F decontamination furnace from which it emerges as scrap metal.

The inert parts of the bomb, although presumably clean, are passed through another 30-foot-long, 1500°F furnace and also emerge as scrap metal. The GB is piped to the chemical process facility described above where it is hydrolyzed to form brines which are spray dried and stored.

As with the Honest John facility, all operations are carried out under negative air pressure; and all vent air is processed through a 1500°F afterburner and an elaborate scrubbing system which includes nine separate scrubbers.

(3) The bulk mustard disposal plant is set up to handle one-ton bulk containers, not munitions; and the mustard is disposed of by incineration.

The one-ton containers are held indoors until the contents are thawed (mustard "gas" melts at 56°F), and are then transferred to unload booths where the contents are drained to storage tanks. The empty containers are then sent to one of a pair of furnaces five feet high by four feet wide by twenty feet long where any residual mustard is pyrolyzed and burned. The empty containers, now decontaminated, are sent to salvage.

The liquid mustard is destroyed in a chemical incinerator ten feet in diameter, 27 feet long and lined with K-2600 fire-brick. It has flame temperatures up to 4000°F and a retention time of six seconds at a throughput of 25 pounds of mustard a minute. This furnace (as well as the one-ton container furnaces) discharges its gases through a 30-foot-long, high-temperature flue in which afterburning can occur if needed for complete combustion.

The furnace gases leave the flue at temperatures up to 2000°F and pass to quench towers where they are cooled to 150-180°F by caustic sprays, through packed column scrubbers with

more caustic, and finally through a series of five electrostatic precipitators.

The scrubber brines are evaporated to dryness in a 24-foot-diameter spray dryer at a feed rate of up to 30 gallons per minute. The salt is collected in hoppers, compacted and put into long term storage in 55-gallon drums.

It is planned to use these facilities to transfer phosgene from old bulk containers to new ones starting in late 1976. The phosgene, being a valuable item of chemical commerce, called carbonyl chloride, will be transferred to DOT-approved shipping containers and sold as a bulk chemical. The air will be processed through a 6000 cfm caustic-packed scrubber.

b. Tooele Army Depot CAMDS Facility

Tooele's Chemical Agent Munition Disposal System is an automated factory for "un-manufacturing" a chemical munition with total containment of both explosive and toxic contents. Its advanced automation and the advanced emission controls give a valuable preview of what conventional demilitarization could achieve with the advanced technology now in use or under development (117). As currently configured, CAMDS handles two items, M-55 rockets and bulk Mustard containers.

(1) The M-55 Rocket is a chemical munition about five feet long and five inches in diameter. Its forward half is filled with liquid GB and a burster, and its rear half is a rocket motor. It is shipped and stored in a close-fitting fiberglass case which doubles as a launching tube.

For demilitarization at CAMDS, the entire munition, case and all, is loaded by hand onto a conveyor cradle outside the door of the ECC (Explosive Containment Cubicle). The ECC is an 85-ton steel pressure vessel within which the toxic munition sawing and punching operations are carried out. It is designed to totally contain the explosive and toxic products even if the entire munition were to detonate in the worst possible mode.

Under computer control, the ECC door opens, the conveyor cradle penetrates it, a ram pushes the rocket-and-case onto another cradle inside the door, the ram and conveyor retract, and the ECC door closes and seals. Still under computer control, clamps secure the munition, punches penetrate it to drain off the agent into tanks, and six circular hacksaws cut the munition

into seven cylindrical pieces a foot or less long. The pieces are conveyed to a deactivation furnace which is a 1.5-scale version of the APE-1236 and operates at a temperature of 1000°F. Propellants, explosives and agent remnants are burned in this deactivation furnace, and the emerging metal parts are further incinerated in a one-hour trip through a 1000°F conveyor tunnel from which they emerge as uncontaminated scrap metal.

The liquid agent drained from the weapon is hydrolyzed with caustic to yield a non-toxic brine consisting mainly of sodium fluoride and sodium di-isopropylmethylphosphonate. The brine is evaporated to dryness in a spray dryer, and the dry salt is compacted and drummed for indefinite retention.

The gases from the ECC air sweep, the various furnaces and the spray dryer are led through a blast attenuator section, a cyclone, a slagging afterburner, a cooler, a caustic water quench, a venturi scrubber, two packed column absorbers, a demister - and up the stack. The slagging afterburner is a vertical combustion unit operating at 1600°F with one second retention time for agglomeration of glass fiber shreds (from the fiberglass rocket motor shipping case) and final combustion of any remaining agent vapors. The venturi scrubber removes particulates and is also a gas quench system (from 1600°F to 150°F). The packed bed containing 170 cubic feet of saddles is charged with an NaOH solution for trace gas neutralization, and the demister is for removal of P_2O_5 which may form in the packed bed. The system is designed to handle 26,000 cfm of hot gases from the furnace.

Besides its safety function of eliminating hazardous manual operations, the elaborate automation and computer control also enhances the reliability of operations. The computer continuously monitors the status of munition position sensors, door seals, safety interlocks, bearing temperatures, motor load levels, air pressures and flows, and other critical operating factors, and it will lock out operations unless all factors are within proper limits.

(2) The bulk Mustard operation is very similar to the mustard operation at RMA, described above, somewhat modernized with newer equipment and some lessons learned from the RMA operation. Complete one-ton containers of mustard are loaded into a large special furnace and large holes are punched in the top sides. The containers are not drained; the 600°F heat of the furnace volatilizes the mustard and the vapor is led to a "fume burner" where it is combusted. The exhaust of the fume burner goes

through an afterburner and thence to the exhaust gas treatment system. The empty one-ton container moves on to a 1000°F furnace section to make sure that all the mustard in it has indeed been pyrolyzed. The decontaminated metal parts are sent to salvage.

The special furnace is a three-compartment unit whose floors are steel-and-firebrick railroad cars. The first section of the furnace is for container punch. The second is for agent volatilization and operates at 600°F with deficient oxygen. The third section is the burnout section for the container and operates at 1000°F.

All off-gases and furnace exhausts are led to the air pollution control system which consists of a series operation containing: two afterburners, a venturi scrubber, a packed bed and a demister. All components are similar to those in the M-55 system except for the afterburners. Both of the afterburners in the mustard system are 1000°F units to assure combustion of the volatilized mustard from the second stage of the furnace.

SECTION VII

PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

35. INTRODUCTION

Although complete conclusions and recommendations are not within the scope of this Phase I Report, nevertheless, some brief, preliminary conclusions can be drawn regarding the demilitarization processes and the effluents produced therefrom. This paragraph deals only with the processes themselves. Preliminary conclusions regarding treatment are presented in subsequent chapters. Six categories of demilitarization are addressed in this paragraph: washout; deactivation furnace; open detonation; open burning; new developments; and advanced technology in chemical demilitarization.

a. Washout

This is an effective process for removal of most explosives, such as TNT and Comp B. It is not effective for removal of many propellants as in rocket motors, or plastic bonded explosives (PBX). In addition, this is an energy-intensive processes. Under the present circumstances of decreasing supply and increasing cost of energy, alternative processes should be investigated to minimize energy consumption.

b. Deactivation Furnace

This is an effective process for demilitarization of small munitions. Although energy consumption is involved, safety is also a paramount consideration, and this may be judged as the most cost-effective process for small munitions demilitarization when all considerations are taken into account.

c. Detonation

This is a simple, safe and cost-effective process for demilitarization of many munitions which are obsolete or unsafe to handle otherwise. No additional energy consumption is involved. The quantities involved are small when compared with the commercial blasting industry (over one million tons/year) (129). Use of this process will always be required to a certain degree.

d. Open Burning

This is also a simple, safe and cost effective process for demilitarization of munitions which are obsolete or unsafe to handle otherwise. Potentially adequate alternatives to open burning are under development and their implementation will depend upon the relative balance among cost, energy implications, and environmental factors.

e. New Developments

Current military plans for development and demonstration of new or improved demilitarization processes are sufficiently comprehensive to provide a range of alternatives, provided that adequate funding is made available for the implementation of these development programs. A potentially useful study could be initiated to examine systematically the energy implications, environmental aspects and cost effectiveness of various alternative new demilitarization development programs. This would be a program which would merit EPA funding support.

f. Advanced Technology

The U. S. Army has developed and demonstrated at Rocky Mountain Arsenal and Tooele Army Depot the most advanced technology presently available for the safe disposal of energetic, toxic and hazardous substances. A potentially useful program

could be initiated by EPA to investigate the application of this technology to the disposal of toxic and hazardous industrial substances as contemplated in the recently enacted legislation in PL 94-469.

CHAPTER III

AIR EFFLUENTS

36. INTRODUCTION

Air pollution can result from several activities associated with demilitarization of conventional munitions. These include washout, deactivation in rotary furnaces, open burning, and detonation. The most significant emissions sources are associated with the combustion processes. New treatment and control systems are under development to abate the problems. Present treatment methods for air pollution control from demilitarization include filtration for particulate matter and scrubber systems for particulates and gases. Combustion process modifications and alternative processes such as fluidized bed incineration and wet air oxidation are under development.

SECTION I

AIR POLLUTION SOURCES AND CHARACTERISTICS

37. INTRODUCTION

This section describes the sources and characteristics of gaseous and particulate effluents. Control technology is discussed in the next section.

38. DEACTIVATION FURNACE

a. The deactivation furnace was developed for demilitarization of small arms ammunition, primers, fuzes, boosters, detonators and miscellaneous small ammunition, and can be used to deactivate certain sectioned bombs and rockets.

b. Effluent gases include NO_x , SO_x , HC and CO. Particulate matter includes metals such as Pb, Hg, Mg and Al. The furnace is normally operated with No. 2 fuel oil with 9-21 gph as a feed rate

(72). Table 3 presents uncontrolled emission levels for combustion of various munitions (120). Generally, uncontrolled emissions are well above allowable emission standards. NO_x levels as high as 8681 ppm are indicated in the table.

39. WASHOUT OF ENERGETIC MATERIALS

a. These systems were developed to wash out and reclaim explosive fills and recover metal parts for reuse or salvage. Water at a pressure of 90 to 125 psi and at a temperature between 180°F and 205°F is jetted into the opening of the filled cavity. Under a combined hydraulic, erosive and melting action, the explosive filler is washed out of the munition.

b. Steam and hot water washout produce distillation and vapor carry over of the organic energetic materials, resulting in air effluents. The sludge remaining from water discharge and evaporation on land (leaching beds) and from the water filters is disposed of by open burning, resulting in additional emissions. Sludge from weekly maintenance and cleaning is also open burned. Casings are "flushed" by open burning to remove all traces of explosives. No information has been provided on the quantity and quality of air emissions from a washout plant.

40. DETONATION

a. Detonation ground operations accomplish the disposal of obsolete and defective munitions by detonation. The ammunition items are placed in pits, primed, and normally covered with earth. The items are then detonated. Detonations produce effluent gases, particulate matter, shock, noise and some non-volatilized residue. These environmental factors are inherent in this disposal method, and it is unlikely that they can be eliminated with current practices.

b. The capabilities of detonation grounds are dependent on established explosive limits. The explosive limits are based on surrounding conditions, the size of demolition ground, and its location. Weather conditions as well as air and water standards can also have an effect on detonation capacity.

c. Table 4 illustrates the emission products of detonation for various explosives (94).

d. Table 5 shows the results of Russian studies on grain-granulite 80/20 and TNT (26). These studies were done to

TABLE 3. UNCONTROLLED EMISSIONS FOR COMBUSTION OF MUNITIONS (120)

Munition	Test No.	Average NO _x ppm	Particulate Concentration gr/scfd	Particulate Mass Rate lb/hr	Particulate Composition % Pb	Average Part. Loss On Ignition % Comb.	Particulate Bulk Density gr/cc	Average SO ₂ ppm	Average SO ₃ H ₂ SO ₄ ppm	HCl ppm
Cartridge 7.62 mm 4 ball M80 1 Tr. M62	P7	3226.	3.3763	33.90	60.1					1.0
	P8	2312.	3.4142	34.09	50.6					1.0
Cartridge Cal 30 Tracer M1	P2	7732.	8.6450	85.64	57.7					
	P3	8178.	9.9178	92.99	34.0					
Cartridge Cal 50 Tracer M17	P6	4732.	9.1559	82.02	6.4					0.4
	P16	4536.	6.4102	63.73	15.5					0.1
Cartridge Cal 50 API M8	P4	6799.	1.4952	15.10	47.9	23.91	.75			0.2
	P5	8681.	1.7627	16.97	22.6	22.00				0.5
Booster M21 A4 Assembled	P14	117.	1.5580	16.92	9.7	7.36				
	P15	75.2	.3559	3.91	20.1	12.61				
Booster M21 A4 Disassembled	P11	538.	.3582	3.56		88.73	.176			
	P12	285.	.3245	3.11		88.39				
Fuze MTSQ M 502 with Booster	P17	460.	.8544	9.34	14.2	15.96				1.0
	P18	531.	.5138	5.76	30.0	27.43				1.0
Fuze BD M66 A1	P19	163.	.9281	10.01	18.3	9.61				0.1
	P20	67.1	.6688	7.13	48.9	8.84				1.0
Primer Percussion M28 B2	P9	49.2	2.1587	21.27	2.6	3.30	.48	39.5	282.4	0.8
	P10	40.6	2.5052	24.08	1.5	6.26				2.0
Primer Percussion M40 A2	P22	68.6	1.6865	17.67	9.8	14.00		18.8	53.2	3.0
	P23	52.9	1.7217	17.51	5.4	11.23				2.0

TABLE 4. DETONATION PRODUCTS OF CONFINED AND UNCONFINED EXPLOSIONS (94)
(values in moles/mole) (ppm)

Product		PETN		Explosive		TNT	
		Confined	Unconfined	Confined	Unconfined	Confined	Unconfined
Name	Symbol						
Carbon Dioxide	CO ₂	3.32	3.50	1.92	1.44	1.25	0.063
Carbon Monoxide	CO	1.61	1.56	1.06	2.65	1.98	5.89
Carbon	C	-	-	0.97	-	3.65	1.01
Nitrogen	N ₂	1.95	2.00	3.68	4.01	1.32	1.36
Water	H ₂ O	3.68	3.45	3.18	2.50	1.60	0.17
Hydrogen	H ₂	0.34	0.51	0.30	1.53	0.46	2.31
Ammonia	NH ₃	0.056	0.0002	0.395	-	0.162	0.022
Methane	CH ₄	0.004	0.0002	0.039	-	0.099	0.0092
Hydrogen Cyanide	HCN	-	-	0.008	0.0006	0.020	0.024
Ethane	C ₂ H ₆	-	-	0.001	-	0.004	-

TABLE 5. EMISSIONS FROM EXPLOSIVES DETONATIONS (26)

Explosive	Ore, Rock	Strength Indicator of Rock According to Scale of Prof. Protod'yakonov	Content of Noxious Gases per 1 kg Explosives, l		
			CO	NO ₂	Total*
Grain-granulite 80/20	Magnetite hornfels	14 - 16	15.5	2.54	32.0
	Magnetite and semioxidized hornfels	13 - 15	13.0	3.33	34.6
	Substandard hornfels and shales	12 - 13	12.2	3.48	34.8
	Shales	10 - 12	10.2	7.0	55.7
Grain-granulite 50/50 TNT	Magnetite hornfels	9 - 10	9.4	7.7	59.4
	Substandard and magnetite hornfels	13 - 15	33.2	2.82	51.5
	Magnetite hornfels	12 - 13	30.8	3.34	52.4
	Substandard and magnetite hornfels	16 - 18	70.2	2.02	83.1
	Magnetite hornfels	14 - 16	65.4	2.91	84.4
	Substandard and magnetite hornfels	13 - 15	57.8	1.54	74.3
		12 - 14	52.2	3.19	72.8

*Calculated relative to carbon monoxide.

simulate blasting in open pit mining rather than explosive disposal. The charges were buried in the ground 10-15 meters for the purpose of breaking loose ore. This may account for the fact that greater amounts of pollutants were formed in these tests than those conducted by Burlington and AEC (Table 4). Although there is no mention of the size of these charges, it is assumed they are several times smaller than the amounts of explosives commonly detonated during demilitarization. The deep burial of small charges may serve to exclude air that could carry the combustion process to completion.

(1) Tests conducted at Burlington consisted of detonating 25 gram charges of HMX, TNT, and PETN in a chamber containing enough air that free oxygen could remain after the explosions. The tests showed that CO_2 , H_2O , and N_2 (all non-pollutants) were the main products formed from all three tests. A slight amount of NH_3 was found dissolved in the water collected from all three tests along with a small amount of NO_x (0.19 ppm of explosive) in the test using TNT (26).

(2) AEC tests were conducted on 15-25 gram charges of tetryl and Comp B in a chamber containing enough air that the composition of gas remaining in the chamber after the blasts still contained 5-10% free oxygen. A gas analysis on both tests revealed the formation of CO_2 and N_2 with only a trace amount of gaseous unburned hydrocarbons. A trace amount of CO was also found in the Comp B test. The trace amounts were less than 0.1% by volume compared to the formation of 10% by volume of CO_2 . No attempt was made to collect H_2O and it was allowed to condense in the chamber (26).

41. OPEN BURNING

a. Burning ground operations consist of open burning of propellants, pyrotechnics, explosives and other unserviceable combustible materials common to demilitarization operations. Unserviceable combustibles are generally used to ignite the energetic material after it has been spread thinly on the ground. Also, some explosive items which cannot be washed out are burned out, providing the explosive is accessible. Capacities of burning grounds vary according to geographical location, explosive limits and size of the areas. Explosive limits are dictated primarily by safety factors.

b. The open burning method of disposal produces effluent gases, particulate matter, and some non-volatilized residue. These

environmental factors are inherent to this method of disposal, and it is unlikely that they can be eliminated with current practices. However, by controlling the quantity and nature of material burned and using modified methods, both the gaseous and particulate emissions can be reduced to minimize environmental effects.

c. Table 6 illustrates the gaseous combustion products evolved from the burning of various propellants and explosives (94). The data presented in Table 6 constitute an attempt to quantify the emissions generated during the complex phenomena of open burning, for abatement and control purposes. However, the results are erratic, since no accepted methods exist to measure the quantities.

d. Burlington has conducted tests by burning approximately 0.6 gram of various explosives (26). Assuming that the products formed in small scale tests are in the same proportion as those produced in large scale open burning, the results obtained are shown in Table 7.

e. Estimated quantities of air pollutants generated by the open burning of PEP wastes and PEP-contaminated wastes were calculated by multiplying waste generation data by emission factors which were selected to represent the open burning of such wastes (130). The data are based upon waste burning records kept by the various installations. The data on PEP wastes have a high degree of accuracy, since records of all PEP materials must be maintained. The PEP-contaminated waste records are based upon truckload quantities delivered to the burning ground. Estimations of air pollutant emissions from the open burning PEP wastes and PEP contaminated wastes are listed in Tables 8-9. A summation of emission estimates for PEP wastes for 1975 is provided in Table 10 as pounds per month, and were based upon emission factors developed by laboratory scale test burns of one gram quantities of TNT in a simulation of open burning. No other quantitative data exist. The following emission factors were used:

NO_x - 150 lb/ton of TNT open burned
CO - 56 lb/ton of TNT open burned
HC - 1 lb/ton of TNT open burned
Particulates - 180 lb/ton of TNT open burned

TABLE 6. EMISSIONS FROM BURNING OF ENERGETIC MATERIALS (94)
(Pounds of Gas Per Ton Burned)

Combustion Product	Black Powder	HEX Tritonal	Compositions B, B3, A, C, Cyclitol	TWT Explosive D Octol	Single Base Propellant	Double Base Propellant	Composite Propellant	Triple Base Propellant	NACO Propellant	MOSOL	Tarrier Sustainer Propellant
Carbon Monoxide	-	891.6	939.7	1,194.1	798.2	327.4	-	794.4	697.2	1,049.4	828.8
Carbon Dioxide	844.0	-	337.4	189.2	757.6	1,137.0	19.0	142.6	737.2	290.2	674.2
Nitrogen	204.8	6.3	589.8	369.8	239.6	297.0	-	-	216.0	276.2	241.0
Water	-	978.2	2.3	31.0	146.6	163.4	-	480.7	138.4	333.4	140.2
Hydrogen	-	41.2	39.8	36.9	46.0	26.4	-	43.0	49.0	29.4	53.2
Carbon	18.8	12.4	-	174.8	-	-	-	-	61.4	-	44.8
Methane	-	-	1.6	4.16	10.4	14.4	-	13.8	4.52	0.1	-
Ammonia	-	-	0.03	0.03	0.03	-	-	2.72	-	0.65	-
Hydrogen Sulfide	-	-	-	-	-	-	-	-	-	3.0	-
Hydrogen Cyanide	-	-	2.54	-	-	-	-	2.21	-	0.88	-
Potassium Hydroxide	-	-	-	-	-	-	-	-	13.2	-	-
Lead	-	-	-	-	-	-	-	-	17.8	-	17.8
Aluminum	-	21.54	-	-	-	-	-	-	-	-	-
Aluminum Oxide	-	48.76	-	-	-	-	120.0	-	-	-	-
Potassium	273.8	-	-	-	-	-	-	-	-	-	-
Carbon Oxisulfide	330.2	-	-	-	-	-	-	-	0.256	-	-
Sulphur	0.6	-	-	-	-	-	-	-	-	-	-
Carbon Disulfide	26.3	-	-	-	-	-	-	-	-	-	-
Hydrogen Chloride	-	-	-	-	-	-	340.0	-	-	-	-
Sulphur Dioxide	-	-	-	-	-	-	1.0	-	-	-	-
Atmospheric Constituents	-	-	-	-	-	-	1,200.0	-	-	-	-
TOTAL GAS EMISSIONS PER SYSTEM	1,698.5	2,000.0	1,913.2	1,999.9	1,998.4	1,965.6	1,680.0	1,479.4	1,934.9	1,983.2	1,999.0

Typical propellant compositions are given in Table 2, Chapter I.

TABLE 7. ESTIMATED DAILY POLLUTION EMISSIONS FROM BURNING EXPLOSIVES (26)

Pollutant	Burning 3.8 Tons PBX-9404	Burning 3.8 Tons LX-09	Burning 3.8 Tons Comp B-3	Burning 3.8 Tons TNT	Autos Adjacent to Plant
Carbon Monoxide (lb)	23	4	19	213	2499
Oxides of Nitrogen (lb)	144	110	141	570	192
Hydrocarbons (lb)	0	0	0	4	218
Phosphorous Pentoxide (lb)	49	0	0	0	No Standard
Hydrochloric Acid (lb)	87	0	0	0	No Standard
Hydrofluoric Acid (lb)	0	23	0	0	0
Soot (lb)	0	0	0	684	No Standard

NOTE: The automotive figures are based on 10,380 daily vehicles (Iowa Highway Commission count) travelling 2.8 miles each (along the Burlington defense plant perimeter). Each vehicle is assumed to barely comply with Federal Emission Standards for automobiles as published in Environmental Science and Technology. The value of 3.8 tons is the average daily amount burned for all explosives combined from both divisions A and B at the Burlington Plant.

Typical explosive compositions are given in Table 2, Chapter I.

TABLE 8. 1975 MONTHLY EMISSIONS FROM PEP WASTE (26)

Installation	NO _x	HC	CO	Particulates	SO ₂
(pounds per month)					
<u>ARMY AMMUNITION PLANTS</u>					
Radford	9,000	60	3,360	10,800	*
Iowa	6,480	40	2,420	7,780	
Longhorn	4,440	30	1,660	5,330	
Milan	3,620	20	1,350	4,340	
Volunteer	3,060	20	1,140	3,670	
Holston	2,850	20	1,060	3,420	
Louisiana	2,070	10	770	2,480	
Joliet	1,660	10	620	2,000	
Indiana	930	10	350	1,120	
Lake City	870	10	320	1,040	
Kansas	580	neg	220	700	
Lone Star	520	neg	200	630	
Twin Cities	10	neg	neg	20	
TOTALS	36,090	230	13,470	43,330	
<u>ARSENALS</u>					
Pine Bluff	2,060	10	770	2,470	*
Redstone	1,740	10	650	2,090	
Picatinny	800	10	300	950	
Edgewood	40	neg	20	60	
TOTALS	4,650	30	1,740	5,570	
<u>DEPOTS/DEPOT ACTIVITIES</u>					
Seneca	10,200	70	3,810	12,240	*
Anniston	4,950	30	1,850	5,940	
Lexington-Blue Grass	4,540	30	1,700	5,450	
Letterkenny	4,520	30	1,690	5,420	
Tooele	1,710	10	640	2,050	
Red River	1,460	10	540	1,750	
Sierra	1,440	10	540	1,730	
Savanna	1,260	10	470	1,510	
Navajo	570	neg	210	680	
Pueblo	80	neg	30	90	
Umatilla	20	neg	10	20	
Wingate	neg	neg	neg	neg	
TOTALS	30,750	200	11,490	36,880	
<u>OTHER</u>					
Fort Sill	2,880	20	1,080	3,460	*

*No data on sulfur dioxide emissions.

TABLE 9. 1975 MONTHLY EMISSIONS FROM PEP-CONTAMINATED WASTE (26)

Installation	NO _x	HC	CO	Particulates	SO ₂
(pounds per month)					
<u>ARMY AMMUNITION PLANTS</u>					
Holston	7,130	35,600	101,000	19,020	*
Kansas	780	3,900	11,000	2,080	
Milan	470	2,360	6,670	1,260	
Lone Star	390	1,950	5,520	1,040	
Radford	190	940	2,670	500	
	120	600	1,700	320	
Sunflower	100	500	1,400	260	
Indiana	90	460	1,290	240	
Badger	60	320	890	170	
Joliet	50	240	690	130	
Volunteer	40	220	630	120	
Longhorn	20	120	340	60	
Louisiana	20	80	240	40	
Lake City	neg	10	20	neg	
TOTALS	9,460	47,300	134,060	25,240	
<u>ARSENALS</u>					
Pine Bluff	230	1,140	3,200	600	*
Picatinny	90	460	1,300	250	
Redstone	20	120	340	60	
Edgewood	10	60	160	30	
TOTALS	350	1,780	5,000	940	
<u>DEPOTS/DEPOT ACTIVITIES</u>					
Seneca	2,310	11,600	32,700	6,170	*
Savanna	360	1,790	5,070	960	
Letterkenny	280	1,400	3,960	740	
Red River	100	510	1,450	270	
Lexington-Blue Grass	90	440	1,240	230	
Sierra	70	360	1,030	190	
Anniston	60	300	860	160	
Tooele	neg	10	20	neg	
Umatilla	neg	neg	10	neg	
TOTALS	3,270	16,410	46,340	8,720	

*No data for sulfur dioxide emissions.

TABLE 10. SUMMARY OF 1975 EMISSIONS (72)
(pounds/month)

Type Waste	Location	NO _x	HC	CO	Particulates
PEP	Army Ammunition Plants	36,090	230	13,470	43,330
	Arsenals	4,650	30	1,740	5,570
	Depots/Depot Activities	30,750	200	11,490	36,880
	Others	<u>2,880</u>	<u>20</u>	<u>1,080</u>	<u>3,460</u>
TOTALS		74,370	480	27,780	89,240
PEP-Contaminated	Army Ammunition Plants	9,460	47,300	134,060	25,240
	Arsenals	350	1,780	5,000	940
	Depots/Depot Activities	3,270	16,410	46,340	8,720
	TOTALS	<u>13,080</u>	<u>65,490</u>	<u>185,400</u>	<u>34,900</u>

Emission estimates for PEP-contaminated waste were based upon emission factors for open burning as presented in "Compilation of Air Pollution Emission Factors (Revised)," U. S. Environmental Protection Agency, Office of Air Programs Publication No. AP-42, February 1972. The reader should understand that actual field test data on open burning of these types of wastes are practically non-existent. No emission factors are available for other specific PEP wastes. Thus pollutants such as hydrogen chloride and hydrogen fluoride cannot be placed in any meaningful perspective. Since most energetic materials do not contain sulfur, sulfur dioxide emissions from PEP-contaminated waste can be considered negligible. The emission factor for TNT was assumed to be representative of the general classification of PEP wastes.

SECTION II

AIR POLLUTION CONTROL

42. INTRODUCTION

Development and implementation of air pollution control associated with emissions from deactivation furnaces, washout plants, detonation, and open burning have been progressing at a rapid rate during the last few years by addition of control devices or process changes.

43. DEACTIVATION FURNACE EMISSION CONTROL

a. The Army is in the process of installing fabric filter dust collector systems (APE 1276) for particulate removal on the standard APE 1236 deactivation furnaces (Table 11) (28). The system includes a baghouse to accommodate a gas flow of 4500 acfm at 400°F. There are 100 Nomex bags with an A/C ratio of 4.8 to 1. A cyclone removes larger material, and a cold air damper controls the temperature in the baghouse. The design pressure drop range is 1/2 to 4" H₂O for the baghouse and 20 inches for the total system. The equipment price is approximately \$45K.

b. The duct between the furnace and the baghouse has provisions for automatically drawing in cooling or dilution air to mix with the hot furnace gases to reduce them to a maximum of 400°F. If the temperatures start to exceed the limitations of the bags, the gases are automatically "dumped" to the atmosphere and the furnace control panel is signalled to instruct the operator to

TABLE 11. AIR POLLUTION CONTROL SYSTEM FOR DEACTIVATION FURNACE
Installation Schedule (28)

Tooele Army Depot (Munitions Div.)	July 1975 (Prototype Testing Completed June 1976)	AEHA Completed acceptance tests October 1975
Pueblo Army Depot	Initial installation completed Aug 1975 modifications scheduled completion July 1976	
Tooele Army Depot (AEO)	Initial installation completed April 1976 modifications scheduled completion July 1976	
Sierra Army Depot	June 1976	
Umatilla Depot Activity	July 1976	AEHA will con- duct observations for compliance with Visible Emission Regulations
Red River Army Depot (Three Systems)	August 1976	
Anniston Army Depot	August 1976	
Blue Grass Army Depot	September 1976	
Letterkenny Army Depot	September 1976	
Lake City Army Ammunition Plant	October 1976	
Tooele Army Depot (Two Systems-Stock)	October 1976	

stop feeding the furnace until the gases have cooled.

c. The dust laden air enters the baghouse near the bottom and passes through the filter bags, from outside to inside, depositing the dust on the bags. The bags are periodically cleaned by introducing a jet-pulse of air at the top of each bag, causing a momentary reverse flow through the bag and forcing the collected dusts into a hopper at the bottom of the baghouse. The collected dusts are continuously discharged from the baghouse through a rotary air lock. Figure 8 illustrates a typical baghouse. The exhaust gases from the furnace are pulled through the baghouse by an induced-draft fan on the exit side of the baghouse. The I.D. fan is automatically modulated to maintain a desired draft (approximately -0.10 in. H_2O) at the furnace exhaust gas exit as the cooling or dilution air increases or decreases, or as the pressure drop across the baghouse increases. The clean gases are then exhausted.

d. The efficiency of the baghouse was tested for emissions from armor piercing .50 caliber cartridges and the assembled M21A4 booster and are reported in Table 12 (72). Most particulate emission rates are within emission standards. The visible emissions from the baghouse were below applicable standards.

e. One standard deactivation furnace at Tooele contains an experimental two-step liquid scrubber to determine the feasibility of destroying chemical agent material. An afterburner located directly after the rotary furnace has a 0.3 sec hold time at $1500^{\circ}F$ for final combustion of rotary furnace material. NO_x removal experiments have also been conducted on this furnace with a scrubber system including a Venturi followed by a wet packed bed. The wet scrubber system, operating at pH 11, removes about 50% of the NO_x .

f. The Navy has installed a combination fabric filter and marble bed wet scrubber on two standard APE 1236 deactivation furnaces at the Naval Weapons Support Center, Crane, Indiana. The system will be used to evaluate control methods prior to installation of control equipment at other Navy facilities. The air can be treated by the filter or scrubber alone, or both in series.

44. WASHOUT PLANT AND DETONATION EMISSIONS CONTROLS

The emissions from a washout plant consist of solids and vapors emitted during the washout, pelletizing and drying operations. A standard design washout plant has three exit stacks



Figure 8 - Pilot Model Air Pollution Control System.

Reproduced from
best available copy.

TABLE 12. PARTICULATE EMISSION DATA (72)

Run Number Date	Cartridge, Cal 50, APIM8				Booster M21A4, Assembled				Fuse, Base Detonating, M66A2				Cartridge Cal 50, M17			
	1 6 Aug	1a* 6 Aug	2 8 Aug	2a 8 Aug	3 8 Aug	3a 8 Aug	4 8 Aug	4a 8 Aug	5a 7 Oct	6a 7 Oct	7a 7 Oct	7a 7 Oct	8a 8 Oct	8a 8 Oct	9a 8 Oct	9a 8 Oct
Stack Gas Characteristics																
Molecular Weight	28.43	28.85	28.43	28.80	28.51	28.92	28.52	28.92	29.00	29.07	29.13	29.36	29.15	29.36	29.15	29.36
Moisture (%)	2.30	2.77	3.76	3.09	3.15	2.71	2.63	2.63	2.60	2.10	2.03	3.76	3.46	3.76	3.46	3.46
Oxygen, O ₂ (%)	19.78+	18.57	19.78	18.59	20.56	17.74	20.49	17.62	19.03	19.22	20.02	17.85	17.82	17.85	17.82	17.82
Carbon Dioxide, CO ₂ (%)	0.27+	0.27	0.27	0.27	0.14	3.35	0.19	3.23	1.47	1.87	1.99	3.19	2.76	3.19	2.76	2.76
Nitrogen, N ₂ (%)	79.93+	78.53	79.93	78.17	79.30	78.86	79.32	78.78	79.34	78.75	77.95	78.12	78.73	78.12	78.73	78.73
Carbon Monoxide, CO (%)	0.02+	0.27	0.02	0.71	0.00	0.05	0.00	0.37	0.16	0.16	0.04	0.84	0.69	0.04	0.84	0.69
Temperature, °F	291	207	194	169	288	230	298	235	182	110	125	228	232	228	232	232
Stack Characteristics																
Velocity (ft/sec)	25.15	26.52	24.99	24.11	30.82	27.05	29.99	22.53	30.54	46.76	43.58	30.67	29.47	30.67	29.47	29.47
Flowrate (acft/sec)	31.36	35.74	36.83	34.73	38.16	35.53	36.60	29.32	43.19	74.79	68.12	41.30	39.15	41.30	39.15	39.15
Mass Emission Rate (MER)(lb/hr)	357.08	0.51	81.92	0.26	24.03	0.20	12.78	0.29	0.17	0.07	0.07	0.22	0.15	0.22	0.15	0.15
Allowable Emission (lb/hr)	-	3.32	-	3.32	-	1.36	-	1.15	2.72	2.72	2.72	3.32	2.98	3.32	2.98	2.98
Percent Removal (%)	-	99.86	-	99.68	-	99.17	-	97.73	-	-	-	-	-	-	-	-
Average Opacity (%)	5	10	10	10	0	0	0	0	0	0	0	10	5	10	5	5
Allowable Opacity (%)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Operational Characteristics																
Feed Rate (T/hr)	0.88	0.88	0.88	0.88	0.21	0.21	0.16	0.16	0.64	0.64	0.64	0.88	0.74	0.88	0.74	0.74
Fuel Consumption (gal/hr)	4.15	4.15	6.99	6.99	16.61	16.61	15.10	15.10	13.80	13.80	13.80	8.66	8.66	8.66	8.66	8.66
Isokinetics (%)																
Barometric Pressure (in. Hg)	106	103	104	110	115	109	112	108	103	84	96	108	105	108	105	105
Barometric Pressure (in. Hg)	25.12	25.12	25.32	25.32	25.32	25.32	25.28	25.28	24.72	24.84	24.94	25.26	25.26	25.26	25.26	25.26
MER as Percent of Allowable	-	15.36	-	7.83	-	14.71	-	25.22	6.25	2.57	2.57	6.63	5.03	6.63	5.03	5.03

*The small "a" denotes sampling done after the baghouse.
+due to leaking bag, gas sample was lost on run 1 so analysis from run 2 was used.

venting each of these operations. All three stacks are about 24" in diameter and have water spray "halo" scrubbers near the top to provide cleanout. The sprays are operated during clean-up operations. A low energy three stage Dugon water spray and baffle scrubber cleans the air stream from the pellet tank and dopp (melt) kettle. A low energy two stage scrubber composed of a water spray section followed by a fin type baffle section cleans the gas stream from the dryer. Table 13 shows the effluent controls and the Army Depot washout plant locations. No emissions data were provided.

b. The control methods presently available for detonation include drilling to provide 10' to 12' deep holes to provide for underground explosion, or bulldozing holes and covering with an 8' to 10' mound. This reduces the smoke and dust cloud. Reducing the explosive charge also reduces emissions.

45. PROPOSED DARCOM DEPOT DISPOSAL SYSTEM

a. Because of the continued potential problems associated with open air burning, the Army is contemplating development of a facility (DARCOM Depot Disposal System) (Figure 9) to process explosive wastes in an enclosed environment, which includes the flexibility and variety of capabilities to accommodate all waste materials which current technology limits to open burning and detonation.

b. The disposal processing facility will consist of three basic reactor units: fluidized bed reactor; confined detonation unit; and a decontamination oven. Each of these will be multi-purpose and will complement the other in accomplishing an environmentally acceptable disposal process. All of the reactor units will be serviced by a single, highly-flexible exhaust gas treatment system.

(1) The Fluidized Bed Reactor will accomplish disposal of all combustible material. It represents a process system which offers several advantages over conventional incineration. The operating temperature conditions in a fluidized bed reactor can be readily controlled within very narrow ranges, a factor which makes possible the incineration of carbonaceous waste while minimizing the generation of noxious fumes and particulate matter. When a combustible particle is added to the bed, transfer of energy to this particle is rapid, and the particle quickly

TABLE 13. WASHOUT PLANT EFFLUENT CONTROL (117)

Depots	Air						Water			
	Dust & Fume Collector (Pellet Sec)			Dryer Exhaust Scrubber			Dust Collector (Dryer Pkg Area)		Fume Exhaust Stack w/o Sec	
	Inst	Sched	Inst	Sched	Inst	Sched	Inst	Sched	Act Charcoal Filter Sys (Under Dev)	Inst Sched
Anniston	X		X		X				X	X
Ft. Wingate	X		X				O		X	O
Lexington-Blue Grass	X		X		X				X	X
Letterkenny	X		X		X				X	X
Navajo	X		X		X		O		X	X
Pueblo	X		X		X		X		X	X
Red River	X		X		X		X		X	X
Savanna	X		X		X		X		O	X
Tocele	X		X		X				X	X
Umatilla	X		X				O		X	O

O Not Scheduled

PROCESS DIAGRAM

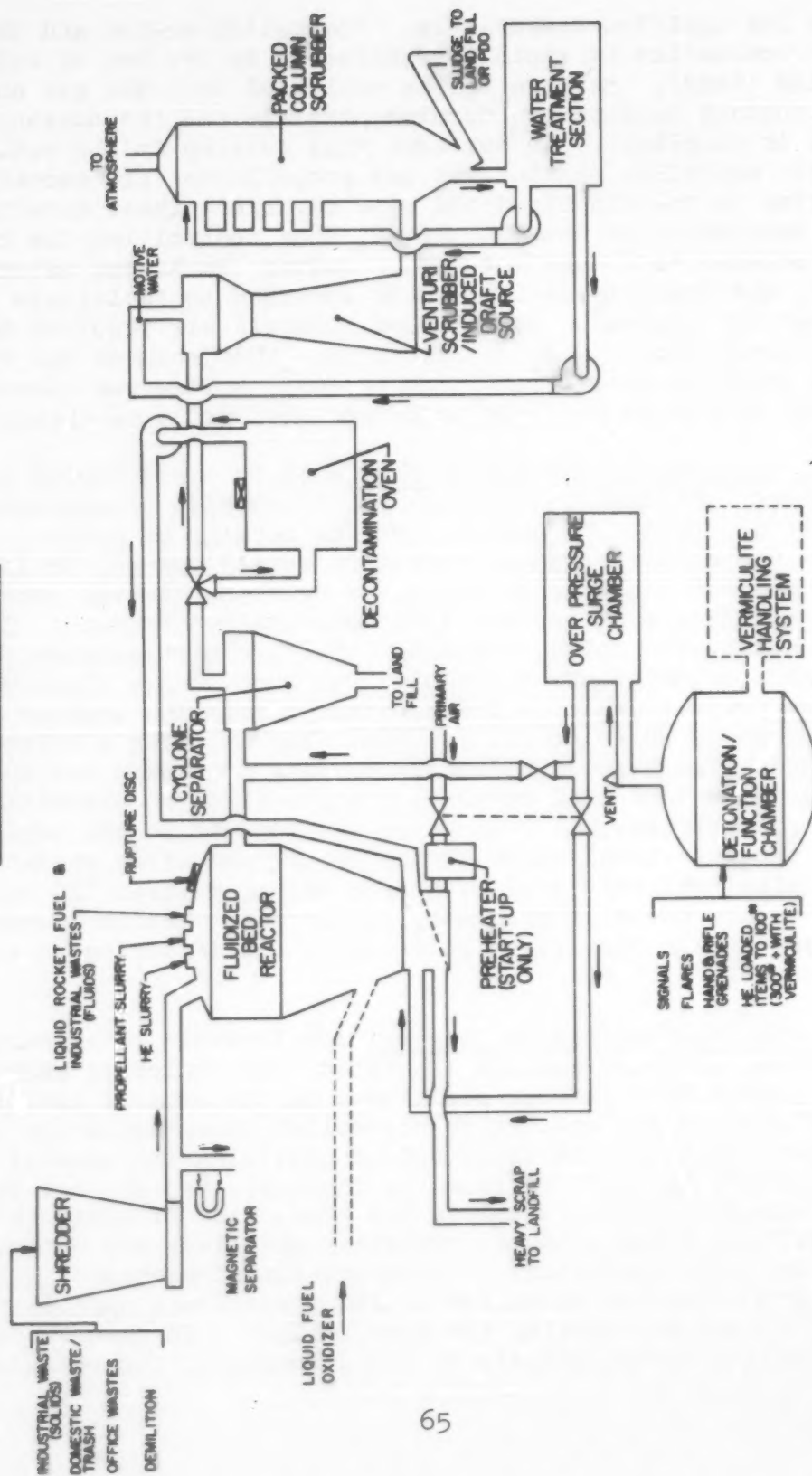


Figure 9 - Process Diagram - DARCOM Depot Disposal System (80)

reaches its ignition temperature. Combustion begins and the heat of combustion is rapidly transferred to the bed of solid particles (sand). Because of the motion of both the gas and the solid, contact between the burning particle and the oxygen in the gas is excellent. No hot zone will develop in the bed. Energetic materials (explosives and propellants) are amenable to combustion in the fluidized bed reactor, since these materials can be introduced as water slurries, thus controlling the heat energy release to a constant BTU value. Packaging materials, dunnage, and domestic wastes can be shredded to facilitate uniform feed and constant BTU value. Excess air required to sustain combustion can be as low as 5%. This reduces the formation of oxidized gases, resulting in small volume gas cleaning equipment needed to meet air pollution standards, particularly NO_x .

(2) The Confined Detonation Chamber will be a reinforced concrete blast containment structure for detonation of explosives in quantities up to 100 pounds, and for burning of pyrotechnics and munitions which cannot be safely opened, or for which disassembly is uneconomical, or whose explosives charge exceeds the limits of the APE 1236 deactivation furnace. The chamber attenuates noise, contains explosive particulates, and allows gaseous emissions to be directed through gas cleaning equipment prior to release to the atmosphere. The chamber can be exhausted in three to ten minutes, thus allowing a relatively short cycle time between detonations. All necessary safety features can be interlocked to prevent any accidental detonation or burning of munitions. Included are windows in the control room to provide visual surveillance before and after operation to determine that all safety features are operative. An emergency entrance hatch is provided, should main chamber openings become blocked in the closed position by debris during an explosive event.

(3) In the Decontamination Chamber, considerable metal parts, projectiles, and bomb casings generated from explosive washout will be placed in a chamber positioned in the exhaust gas line of the fluidized bed reactor to accomplish decontamination by "inductive" heating. An advantage of utilizing the exhaust gases ($1,000^{\circ}\text{F}$ to $1,400^{\circ}\text{F}$) from the fluidized bed reactor is that the low oxygen content minimizes the production of oxide emissions, while sufficient temperature completely pyrolyzes any contaminant to an inert condition. The decontamination chamber will include provision for expansion of its operational capability to serve as a burn-out station for some fillers. To assure efficient cleaning before release to the atmosphere, the emissions

from the decontamination of metal components or burn-out will pass directly to the gas cleaning equipment and - if necessary - may be returned to the fluidized bed reactor for additional oxidation of effluents which otherwise would become secondary emissions.

c. Air pollution control equipment will be selected to scrub gaseous effluents which may be grouped into four categories of emission groupings in the following order of difficulty: (1) burning of propellants and explosives; (2) signals, flares, smoke, and incendiary items; (3) thermal decontamination of metal parts; and (4) burning of dunnage, packing materials, and ammunition maintenance operations scrap. The philosophy of air pollution control is to "prevent it" or "correct it". Air pollution can be prevented by designing the process or machinery with control equipment which eliminates or reduces the pollution at its source. The fluidized bed reactor system represents this "control of the source" by reducing or eliminating the production of difficult-to-clean emissions. Because of the relatively low temperatures generated and low excess air, no appreciable nitrogen oxides would be produced. The distillation products would be consumed in the bed. This eliminates unburned hydrocarbons leaving the unit. The results would be cleaner stack emissions with less scrubbing operations, since the primary pollutant would be particulate matter. Capital, operating and energy costs would be high (35a).

d. Control equipment will be Venturi collectors and packed tower scrubbers. The Venturi collects particles to the 0.1 micron level such as metallurgical fumes and zinc and magnesium oxides, and recovers soluble gases. The Venturi design relies on high gas velocities, on the order of 100 to 500 ft/sec through a constriction where water is added. The impact breaks the water into droplets with the fineness of spray determined by gas velocity. The packed tower scrubber removes dust but is primarily designed for gas absorption. Gas-liquid flow is counter-current, and extended surface packings achieve absorption by maximizing the liquid surface while collecting particulates by cyclone action. Particulates, dust, fly ash, etc. are collected in the wet discharge and disposed of to land fill.

e. Source testing will be performed to obtain emission data. Continuous sampling devices which provide accurate records of emissions will be utilized. Monitors using spectroscopic, chromatographic, or chemiluminescent reactions are available for

accurate testing and control of pollutants. Figure 9 is a process flow diagram for the complete system.

46. OPEN BURNING ALTERNATIVES

a. The Problem

Large quantities of unserviceable or unsafe munitions are disposed of by open burning. Also, projectiles demilitarized by other processes such as washout must be flashed to insure removal of all explosive material, and this is often done in open burning areas.

b. Alternatives

An acceptable alternative for open burning would be to use an incinerator, but safety problems make this difficult. However, the DARCOM Depot Disposal System (Figure 9) could provide for controlled burning. Presently the control of the timing and amount of each open burn, as well as consideration of local weather conditions will reduce the emissions. The use of air curtain devices may also reduce emissions.

c. New Technology Incineration Equipment

(1) The long range solution is to complete research and development and testing of alternatives such as rotary kiln incineration and fluidized bed combustion (87).

(2) A flashing furnace to replace open burning of projectile casings has been designed and will be installed at Tooele. The furnace will operate at 1800°F on 8000 lb/hr of munitions (121). No air pollution control equipment is presently planned for this facility. The majority of the explosives are to be removed by washout prior to entry of the munition into the furnace. Munition sizes and weights are to vary from 2" diameter and 12" long to 11" diameter and 50" long, and from 10 to 500 pounds each. The furnace is charged by a self-moving, refractory-lined transfer car with one zone of control which holds four cars.

(3) The Navy is constructing a "Western Demilitarization Facility" at Hawthorne, Nevada to demilitarize the full range of DOD conventional munitions without open burning or detonation (1, 106, 122). The major source of potential air pollutants at this facility will be from: (1) the combustion of material from the explosives washout system; (2) deactivation

(popping) of ordnance items containing small quantities of explosives or propellant; and (3) the flashing of casings to insure complete removal of explosives.

(a) Combustion of explosives after washout will be conducted in two large rotary kilns which will slurry feed a water and explosive mixture. The furnace will be designed based upon criteria obtained from a pilot scale furnace of this type under development at Radford AAP. Initial decisions of responsible individuals indicate that an afterburn chamber will provide adequate air pollution control. No other control device has yet been selected, but it was indicated that such equipment could be added, if required, after the system is operational. The proposed rotary flashing furnaces will include baghouse systems for particle control.

(b) The demilitarization equipment will also include:

- Large items rotary furnace system for destruction of energetic material. The basic design is that of APE 1236 deactivation furnace, with heavy-duty retort.
- Small items rotary furnace system to be used for small fuzes and the primers of small cartridge cases. The basic design is as at NWSC Crane. A common baghouse control system is proposed for both the large and small items rotary furnaces.
- The large items flashing furnace system is to be used to burn off residual explosives from munitions which are too large to be passed through the large items rotary furnace. This is to replace open-field burning methods with their uncontrolled emissions. Two flashing furnaces appear to be desirable: one to handle smaller items on a continuous movement basis; the other to handle large items on a batch basis. A particulate control system for the flashing furnace is not specifically identified.

SECTION III

REVIEW OF DEVELOPMENT TRENDS IN EXPLOSIVES AND PROPELLANTS WASTE INCINERATION

47. RESEARCH AND DEVELOPMENT

Problems concerned with air pollution from open burning have resulted in research by Picatinny Arsenal concerned with a number of incinerator systems (85,84,1)*. Portions of Reference 1 are reviewed below. The following incinerator systems are all designed to handle the problem of waste PEP disposal, and each attacks the problem in a different manner:

- o Vertical, induced draft incinerator
- o Rotary kiln
- o SITPA I & II - (simplified incineration technique for pollution abatement)
- o Wet air oxidation
- o Fluidized bed

The more sophisticated incinerators are under investigation to meet air pollution standards and to provide adequate air and turbulence for proper combustion. Control equipment is planned for some of these incinerators to further reduce the amounts of CO, HC and NO_x released. Because of the total U. S. problem of NO_x emissions, State and Federal environmental agencies are identifying, assessing and promoting the development of cost-effective commercially viable methods for NO_x control from both existing and new stationary combustion sources. It is anticipated that controls will ultimately be required on all waste incinerators, and will take the forms of lowering NO_x formation during combustion, post-combustion removal of NO_x from the combustion products, or catalytic interaction within the process itself.

48. VERTICAL DRAFT INCINERATOR

The forerunner of the PEP waste incinerator program is the vertical draft incinerator. The incinerator was constructed in the 1950's at Picatinny Arsenal to dispose of red water and other contaminated liquid wastes. The unit is a cylindrical steel furnace lined with firebrick. It was modified to dispose of waste PEP in aqueous slurries of 25% weight. Feasibility and safety requirements, particle size reduction, suspension,

*Manufacturing Technology Directorate, Picatinny Arsenal

injection, combustion and baseline gaseous emissions data were established and evaluated. The process consisted of heating the chamber by means of three oil fired burners to a temperature of 1600-1800°F and then injecting the slurry up toward the flame. The downward draft provided by the induced draft enhanced the combustion process by providing combustion air and circulated the gaseous products within the combustion chamber. The gaseous products were then passed through a cyclone separator, and then vented to the atmosphere through a 125' stack. This type of incinerator is presently outdated due to its inefficient operation and poor emission control.

49. ROTARY KILN

The rotary kiln incinerator consists of a refractory lined cylinder slightly inclined to the horizontal at an angle usually between 2-5° and rotating at a slow speed (1-5 rpm). Often both the speed of rotation and inclination of the furnace are variable, so that the flow of material through the cylinder and the retention time for combustion can be controlled. Afterburning facilities can be incorporated in a separate auxiliary chamber, and the equipment generally lends itself to flexible plant layout. By rotation, these furnaces offer the advantages of a gentle and continuous mixing of the PEP slurry, but capital and maintenance costs are high. These costs are derived from the mechanical design requirements of both rigidity of the cylinder and close tolerance for the roller path drive as well as the high-temperature seals between fixed and moving parts. Another major disadvantage is the adverse effect of the explosive slurry contacting the refractory lining at elevated temperatures and the detrimental effect on the refractory of cooling and reheating the chamber during shut-downs. This system requires the use of a cooler and scrubber to reduce the gaseous and particulate emissions and exhaust gas temperature prior to the exhaust fan and stack.

50. SITPA I

The Simplified Incineration Technique for Pollution Abatement (SITPA) is an incinerator designed to eliminate the complexity of the systems described previously. The SITPA process involves manually placing PEP waste on a concrete pad or covered ditch and remotely igniting it. The pad has a hood which accepts the combustion gases and draws them into a duct by means of induction fans. The duct is connected to a baghouse which removes particulate matter from the exhaust gases. The gases pass through

the fan and then out the stack. It is possible to hook up several pads to a single baghouse by ducts and a manifold. The system, while simple, does not provide the process control, pollution abatement or safety features inherent in the systems described later.

51. SITPA II

The SITPA II process (APE 1236) is a specially designed, unlined rotary kiln incinerator where the waste PEP is fed into the combustion chamber in cans containing predetermined amounts of the waste PEP, placed at intervals on a conveyor belt. The waste PEP is burned in the combustion chamber, which is heated by oil burners, and the combustion gases are removed from the chamber by an induction fan and then passed through a baghouse to remove particulates. This system could be operated in the semi-continuous mode for long periods of time.

52. WET AIR OXIDATION

This process is fundamentally the aqueous oxidation of waste PEP in a high pressure vessel. The vessel and the water inside are initially heated to 550°F and 400 psi by steam and compressed air. When these conditions are reached, the steam is shut off and the feed started. The ground waste PEP is fed in a continuous aqueous slurry along with compressed air. The PEP wastes are oxidized and the BTU content of the waste is sufficient to sustain the reaction without any supplemental heat input. The vessel is operated typically at pressures in the range of 600-2000 psi and at temperatures between 400 and 600°F. The oxidation products, consisting of gaseous and liquid materials, nitrogen from the compressed air, and a minor quantity of ash, are cooled by the feed stream in a heat exchanger and separated into a gaseous and a liquid stream. The gaseous stream is treated by an afterburner to destroy CO and residual hydrocarbons. A wet scrubber is used to remove NO_x prior to discharge to the atmosphere. The liquid phase is further processed to remove acidity and metallic salts, and the purified water recycled to the slurry-preparation stage.

53. FLUIDIZED BED INCINERATOR

a. The fluidized bed incinerator is a simple and compact system using aluminum oxide (alumina) for the bed material. If large solid grains or chunks of PEP waste are to be disposed of, they must be size-reduced prior to being introduced in an aqueous

slurry (25% by weight). The operation of the fluidized bed involves the forcing of air through the distributor plate at a rate which can be controlled as desired. At low rates, the bed remains in its original "settled" state, with the pressure drop across the bed increasing with the flow rate until it is equal to the downward force exerted by the bed material resting on the plate. The bed begins to expand at this point, which is called "incipient fluidization," allowing more gas to pass through the bed at the same pressure drop. The bed is now fluidized and has all the properties of a fluid.

b. The advantages of this system are that the enriched oxygen of the bed coupled with the heat transfer between the alumina and waste ensures complete combustion, minimizing carbon monoxide and hydrocarbon emissions; the uniform temperature of the bed plus the use of a nickel catalyst limits the formation of nitrogen oxides. The fluidized bed has provisions for the injection of supplemental oil and auxiliary air into the bed to maintain temperature.

c. Combustion is a chemical reaction which requires the contacting of a fuel with oxygen at a temperature above the kindling temperature. Both a high degree of turbulence and adequate oxygen are required to attain complete combustion. Excess air is the amount of air added to a combustion process beyond that required stoichiometrically by the chemical reaction. The auxiliary air nozzles provide excess air to the bed to achieve complete combustion. The bed itself is maintained in a reducing state while the auxiliary air helps provide an oxidizing atmosphere in the upper portion of the bed. The nitrogen present in the combustion products can come from both the air and the fuel. Some of the nitrogen is oxidized, with resultant NO_x being an undesirable product of combustion. The NO_x formed is a function of the combustion temperature, reaction rates, residence time, nitrogen and oxygen concentrations and quench rates. As excess air and turbulence in the fluidized bed chamber are increased, more products of complete combustion are obtained. These products are further reduced by the presence of the nickel oxide catalyst in the bed, which drastically reduces the NO_x concentration in the exhaust gases.

54. EVALUATION OF VARIOUS CONCEPTS

a. The current judgment of knowledgeable Army personnel is that the SITPA II System is the most cost effective system, based on present emission standards (Table 14). This is especially true for LAP plants which have low overall gaseous emissions due to

TABLE 14. SUMMARY - DEVELOPMENTAL INCINERATOR SYSTEMS (1)

Incinerator	Abatement		Cost (Capital & Operating)
	Particulates to <0.1 gr/scf	NO _x to <200 ppm	
Vertical ID	Yes	No	NA (Feasibility Demo Only)
Rotary Kiln	Yes	Marginal	High (Low Comb Eff Scrubber Water Treat)
SITPA I	Yes	No	Low (No Fuel; No NO _x Abatement; Manual, Batch Oper)
SITPA II	Yes	Yes	Low (Fuel Oil; No NO _x Abatement; Manual, Batch Oper)
Wet Air Oxid	Yes	Yes	Medium (No Fuel; Process & Scrubber Water Treatment)
Fluidized Bed	Yes	Yes	High (High Comb Eff; No Scrubber Water Treat)

Power Requirements (35a)

	SITPA II	Redford Rotary Kiln	Fluidized Bed
Equivalent KW	52 KW	141 KW	141 KW
Assume 50% requirements	26 KW	70.5 KW	70.5 KW
Fuel	10 gal/hr	44 gal/hr	20.9 gal/hr
KW equiv/fuel	405 KW	1786 KW	810 KW
Total	431 KW	1856 KW	880.5 KW
Production rates	600 lb/hr	250 lb/hr	250 lb/hr
Energy consumption per lb of waste	.72 KWH/lb	7.42 KWH/lb	3.52 KWH/lb

minimal in-plant industrial operations. In addition, many LAP plants and Army Depots are in remote locations, away from any large cities, and therefore have state compliance standards which can be less stringent.

b. The SITPA II (APE 1236) and associated air pollution control equipment have been selected by ARRCOM as the standard disposal process for bulk waste ammunition for all Army facilities designated to require such a disposal process (35a). In conducting tests burning bulk explosives at rates up to 600 lb/hr, NO_x and particulate emissions were found to be less than those from small arms ammunition in the APE 1236 (35a). The capital cost (\$0.25 million) of the SITPA II (APE 1236) is substantially less than the estimated \$4-6 million for the complete fluid bed incinerator or the Radford rotary kiln (~\$4M) (35a). In addition, operating costs and energy requirements are also cited as advantages of SITPA II over the fluid bed incinerator and the Radford rotary kiln for use at LAP plants and Army Depots. However, the fluid bed incinerator and rotary kiln still appear to be under consideration for application at military PEP manufacturing facilities. An energy comparison of SITPA II, the Radford Rotary Kiln and the Fluidized Bed Incinerator is given in Table 14.

SECTION IV

ECONOMIC ANALYSIS

55. EVALUATION

In the evaluation of alternative systems, it is necessary to consider the economic factors associated with each system. The economic analysis of the fluidized bed incinerator vs. the rotary kiln incinerator was performed by the Mobility Equipment Research and Development Command (MERADC) under the direction of Picatinny Arsenal. The method utilized by MERADC to perform this analysis is the present value unit cost (PVUC) method.

a. This method utilizes a computerized mathematical model to evaluate alternate incinerator designs. The model considers capital costs, operating costs, time horizons, depreciation, interest and other related factors. The output yields the PVUC per pound of material incinerated. The PVUC program was used to evaluate the cost parameters of the fluidized bed vs. the rotary kiln over the various time horizons and load (operating) rates. The data generated from two typical runs (250 and 1000 lb/hr) are shown in Tables 15 and 16 and Figures 10 and 11. The TNT/slurry weight ratio was 25 percent for these calculations (1).

TABLE 15. COST FACTORS FOR THE 250 LB/HR CASE (1)

Yr	Design Capacity (lb/hr)	Oper. Rate (\$)	Quan. Burned (lb/day)	Oper. Schedule	Rotary Kiln Oper. Cost (\$/day)	Fluid Bed Oper. Cost (\$/day)	PVUC Rotary Kiln \$/lb Expl	PVUC Fluid Bed \$/lb Expl	Cost Savings \$/day	Cost Savings \$/Yr*
5	250	33	2000	1/8/5	276.19	141.43	.26358	.22520	76.76	19,190.
10							.25633	.21629	80.08	20,020.
15							.25046	.20906	82.80	20,700.
20							.24581	.20333	84.96	21,240.
25							.24222	.19891	86.62	21,655.
5	250	66	4000	2/8/5	567.03	255.09	.20450	.14102	253.92	63,480.
10							.20088	.13656	257.28	64,320.
15							.19794	.13294	260.00	65,000.
20							.19562	.13008	262.16	65,540.
25							.19382	.12787	263.80	65,950.
5	250	100	6000	3/8/5	1027.63	347.76	.21310	.10946	621.84	155,460.
10							.21068	.10649	625.14	156,285.
15							.20873	.10407	627.96	156,990.
20							.20718	.10217	630.06	157,515.
25							.20598	.10069	631.74	157,935.
5	250	100	6000	3/8/6 MOB	1027.63	344.73	.20479	.09872	636.42	190,926.
10							.20285	.09634	639.06	191,718.
15							.20128	.09441	641.22	192,366.
20							.20004	.09288	642.96	192,888.
25							.19908	.09170	644.28	193,284.
*250 days - (Standard Work Week)										Capital Equipment Cost FBI - \$582,000 (FY 74)
300 days - (Mobilization - 6 Day Work Week)										RK - \$472,000 (FY 74)

TABLE 16. COST FACTORS FOR THE 1000 LB/HR CASE (1)

Yr	Design Capacity (lb/hr)	Oper. Rate (%)	Quan. Burned (lb/day)	Oper. Schedule	Rotary Kiln Oper. Cost (\$/day)	Fluid Bed Oper. Cost (\$/day)	PVUC Rotary Kiln \$/lb Expl	PVUC Fluid Bed \$/lb Expl	Cost Savings \$/day	\$/Yr*
5	1000	33	8000	1/8/5	815.20	282.12	.14212	.08784	434.24	108,560.
10							.13980	.08481	439.92	109,980.
15							.13792	.08235	444.56	111,140.
20							.13643	.08040	448.24	112,060.
25							.13528	.07889	451.12	112,780.
5	1000	66	15000	2/8/5	1165.49	459.05	.09296	.05498	607.68	151,920.
10							.09179	.05346	613.28	153,320.
15							.09085	.05223	617.92	154,480.
20							.09011	.05126	621.60	155,400.
25							.08953	.05050	624.48	156,120.
5	1000	100	24000	3/8/5	1649.51	554.51	.08214	.04063	996.24	249,060.
10							.08136	.03962	1001.76	250,440.
15							.08074	.03880	1006.56	251,640.
20							.08024	.03815	1010.16	252,540.
25							.07985	.03765	1012.80	253,200.
5	1000	100	24000	3/8/6 MOB	1649.51	548.63	.07947	.03690	1021.68	306,504.
10							.07885	.03609	1026.24	307,872.
15							.07835	.03543	1030.08	309,024.
20							.07795	.03491	1032.96	309,888.
25							.07765	.03451	1035.36	310,608.

*250 days - (Standard Work Week)

300 days - (Mobilization - 6 Day Work Week)

Capital Equipment Cost: FBI - \$792,000

RK - \$606,000

Current Year Dollars - FY74 Base

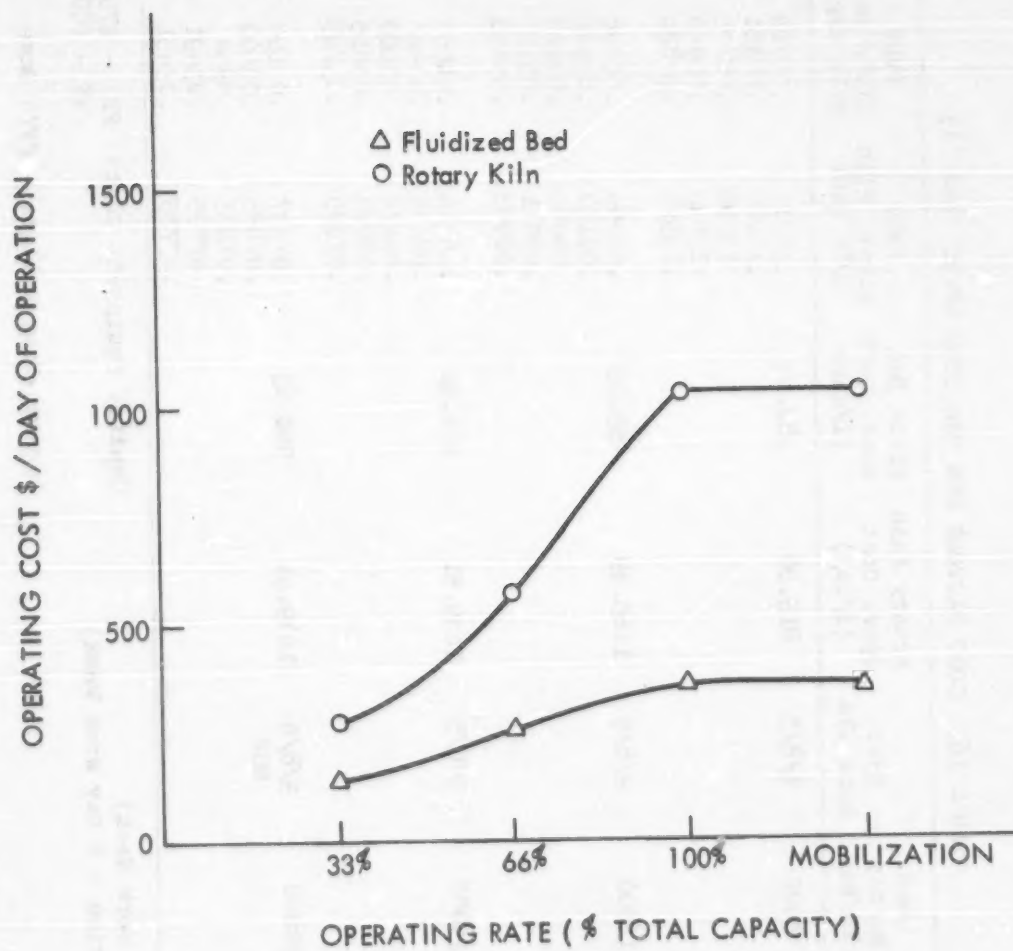


Figure 10 - Comparison of Operating Costs (250 lb /Hr) (1)

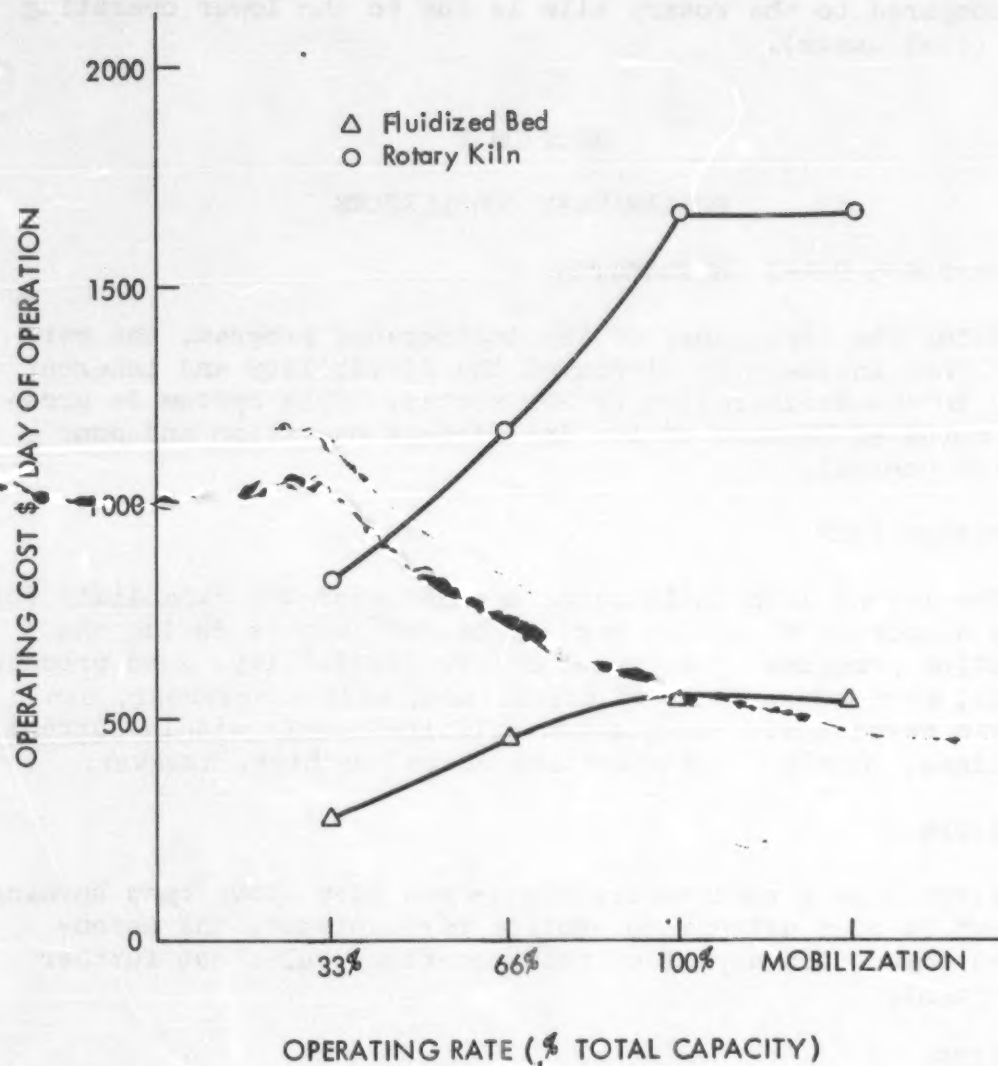


Figure 11 - Comparison of Operating Costs (1000 lb /Hr) (1)

b. By inspection of these tables, it can be seen that the cost savings which can be realized using the fluidized bed incinerator varies from \$19,000/yr up to \$193,000/yr with a 250 lb/hr capacity and from \$108,000/yr to \$311,000/yr with a 1000 lb/hr capacity. The major cost savings attributed to the fluidized bed when compared to the rotary kiln is due to the lower operating costs (fuel usage).

SECTION V

PRELIMINARY CONCLUSIONS

56. VERTICAL DRAFT INCINERATOR

Being the forerunner of the incinerator program, the vertical draft incinerator displayed the feasibility and inherent safety in the incineration of PEP wastes. This system is presently outdated because of its inefficient operation and poor emission control.

57. ROTARY KILN

The rotary kiln incinerator demonstrated its capability for safely disposing of a wide variety of PEP wastes during the evaluation program. The system offers flexibility, good process control, good combustion efficiency and, with a scrubber, can maintain particulate and gaseous emission levels within current guidelines. Capital and operating costs are high, however.

58. SITPA I

SITPA I is a rudimentary system one step above open burning. Although it does attempt to control particulates, the uncontrolled combustion aspect of this technique rules out further development.

59. SITPA II

The SITPA II is a low cost disposal system which has application for use at LAP plants or demilitarization facilities located in non-urban and/or low density industrial areas. This technique does include some combustion controls which remove particulates from the stack gases. There is no attempt to reduce gaseous emissions. Capital and operating costs are low.

60. WET AIR OXIDATION

The wet-air oxidation system has been demonstrated to be a thermally efficient process for disposal of waste explosives and propellants. No supplemental fuel is required to maintain the reaction once the system reaches equilibrium. However, the system operates at high pressure (600-2000 psig) and requires support equipment (e.g., liquid/gas and liquid/solid separators, scrubber) to control the process effluents.

61. FLUIDIZED BED INCINERATOR

The fluidized bed incinerator is a compact disposal system which can safely destroy the PEP wastes and, through the use of a catalyst, conform to current and anticipated standards for NO_x , HC, and CO, with the use of abatement equipment. However, in spite of the high combustion and operational efficiencies, this system is characterized by high capital and operating costs.

62. ECONOMICAL ANALYSIS

The economic analysis technique developed by MERADC is a viable management decision making tool for choosing the most suitable disposal system for each application.

63. GENERAL CONCLUSIONS AND RECOMMENDATIONS

With respect to the major current demilitarization processes, the following preliminary conclusions can be drawn with respect to air effluents.

a. Washout

Although minimal amounts of explosive may escape through the scrubbers in the APE 1300 washout plant, this is not considered to constitute an environmental problem.

b. Deactivation Furnace

Addition of the APE 1276 fabric filter particulate collection system to the APE 1236 deactivation furnace constitutes a significant improvement in air pollution control and should satisfy environmental quality standards for particulates.

c. Detonation

Until the same environmental criteria are applied to the use of explosives in the commercial blasting industry, there is no reasonable basis for criticism of demilitarization of obsolete or unsafe munitions by detonation. Principal products appear to be CO_2 , H_2O and N_2 , all of which are non-pollutants. Covering of the munitions by earth substantially reduces noise and particulates.

d. Open Burning

Alternatives to open burning are in various stages of development, and given sufficient funding, should provide adequate options for the elimination of the environmental problems associated with this process. These alternatives have been reviewed in this Chapter. Support of these development efforts by EPA funding, as well as more detailed evaluation of alternative processes, is recommended.

e. Advanced Technology

The air pollution control systems in use at Rocky Mountain Arsenal and Tooele Army Depot constitute the most advanced technology currently available for treatment of air effluents associated with the safe disposal of toxic and hazardous materials. EPA should take an active role in technology transfer in applying this technology to the solution of problems in industry.

CHAPTER IV

WASTEWATER EFFLUENTS

64. INTRODUCTION

a. Wastewaters result from several activities associated with demilitarization of conventional munitions. These activities include high and low pressure washout; steam melt out; chemical cleaning and rinsing of reclaimed hardware; and scrubber waters from air pollution abatement devices. The most significant current wastewater source is washout, although scrubber waters will increase in quantity and pollution potential as air emission control devices are installed at demilitarization facilities.

b. A variety of treatment and disposal methods are utilized for demilitarization wastewaters. They range from direct discharge onto the land or into receiving waters to extensive treatment and total recycle. There is much similarity in the nature and applicability of treatment processes between wastewaters from loading (LAP) of conventional munitions and those of demilitarization. The former have been presented in a recent comprehensive study (2). This chapter of this report considers demilitarization in two sections: Demilitarization Wastewater Sources and Characteristics; and Demilitarization Wastewater Treatment, Ultimate Disposal, and Costs.

SECTION I

WASTEWATER SOURCES AND CHARACTERISTICS

65. SOURCES

Although the wastewater sources from demilitarization activities are readily identifiable, data on wastewater volumes and pollutant levels are limited. Wastewater originates from: washout operations; meltout; chemical demilitarization; and air pollution scrubber devices. Each source is discussed in this

section, with available wastewater characterization data presented.

66. WASHOUT

a. General

(1) Two basic types of washout facilities are used in demilitarization of conventional munitions. These are: (1) a low pressure-hot water system which is the standard Army design; and (2) a high pressure system of more recent development. Most of the Army washout facilities are the standard model APE 1300 (5) (1974 cost \$600K). The remaining low pressure facilities are predecessor models of the APE 1300, often with modifications on the original installed equipment. The low pressure systems typically operate with water-steam mixtures yielding operating temperatures of 180-205°F. The NWSC Crane high pressure system operates at pressures up to 9,000 psi, and ambient temperature. Longhorn AAP has two high pressure (5500 psi) systems, which operate at flow rates of 10 gpm each.

(2) A variety of munition loads have been processed through washout facilities. The predominant loads are TNT-fill and Composition B. However, washout of other munition loads have also been reported. Table 17 presents data for Army Depots. NAD Hawthorne has also processed Composition B. NWSC Crane is scheduled to handle both Compositions A and B (as well as TNT-fill) in their high pressure system. An experimental system has successfully handled plastic-bonded explosives (1).

TABLE 17. MUNITIONS PROCESSED IN ARMY DEPOT WASHOUT FACILITIES

Location	Comp B.	TNT	Tritonal	Octol
Anniston	X	X		X*
Blue Grass		X		
Fort Wingate	X	X	X	
Letterkenny	X	X		
Navajo	X	X	X	
Pueblo	X	X		
Red River	X	X		
Savanna	X	X		
Tooele	X	X	X	
Umatilla	X	X	X	

*Octol was on test basis. Was not pelletized.

b. Savanna Army Depot

(1) Demilitarization wastewater from Savanna AD results only from the washout facility. This facility was installed in 1952, and upgraded to a partial recycle system in 1971. The facility is currently on stand-by status, although after upgrading it operated on a 24 hour per day basis for approximately one year.

(2) The standard Army APE 1300 model washout facility requires 92,000 gallons of water to charge the system. When in operation, the recycle system is purged of 38,000 gallons of wastewater once each week. This wastewater is treated as described in Section II of this chapter.

(3) Raw wastewater characterization data are limited. Samples at 60°C, analyzed for TNT during 1971 and 1972, were reported to have the following TNT levels (22):

<u>Sample Date</u>	<u>TNT, mg/l</u>
16 Dec	540
23 Dec	1160
14 Jan	539
21 Jan	300
28 Jan	720

These values compare with a theoretical solubility of TNT at 60°C of 675 mg/l.

(4) Wastewater samples analyzed in 1961, prior to the installation of the recycle system when water was utilized on a once through basis, had the values presented below (23):

<u>Raw Wastewater</u>			
<u>Parameter</u>	<u># 1 Line</u>	<u># 2 Line</u>	<u>Clarifier Effluent</u>
pH	8.0	7.8	8.2
Alkalinity	244	230	246
Nitrite	135	277	216
Nitrate	480	509	516
Aluminum (Sol.)	190	76	176
TNT (Sol.)	14	14	23
Diss. Solids	675	533	355
Total Solids	850	652	476

The effect of recycle use on TNT levels is obvious by comparison of the 1961 results with those obtained in 1971-72. The high soluble aluminum level observed at pH 7.8-8.2 is anomalous, since theoretical aluminum solubility is much lower in the pH range reported.

c. Letterkenny Army Depot

The Letterkenny AD washout facility was installed in 1972, replacing an earlier system put into service in 1955. The new APE 1300 washout plant ran continuously (2 shifts/day, 5 days/week) from the time of installation until approximately June, 1975. It is currently not active, due to a lack of munitions on-site for washout demilitarization. During operation, it ran TNT- and Composition B-filled munitions, with the bulk (approximately 90 percent) being TNT-fill. At full-scale operation, the washout facility processed 3200-3500 rounds per day of 90mm (TNT-filled) projectiles. Both TNT and Composition-B were recovered and pelletized for sale. The washout plant operated with a water recycle system, with the water treated as described in Section II and reused. The capacity of the recycle system is 18,000 gallons. This water is discharged only when the washout facility switches from one type of explosive to another (e.g., TNT to Comp. B). Limited waste characterization data are available on the discharge waters (Tables 18 and 19). During normal operation, ~~water is lost by evaporation from the process and replaced as necessary by fresh water.~~ Cleanup water for the washout plant discharges into the recycle reservoir and is used as part of the system makeup water. The system is reported to have been dewatered only three times during the period 1972-1975 (114).

d. Red River Army Depot

A washout facility was installed at Red River AD in the mid-1950's, and was used intermittently until 1972 for TNT filled artillery shells, bombs and rocket warheads. The washout system is a conventional APE 1300 Army unit with partial water treatment and recycle of water. Washout water treatment is described in Section II of this report. This washout system operates at a temperature of 190-195°F. Water is discharged from the system only in the event of equipment breakdown or when the system is placed on inactive status. The washout facility is reported to have handled up to 10,000 lb/day of explosives, although typical production averaged 8,500 lb daily, for a single work shift. The capacity of the recycle water system is

TABLE 18. CHEMICAL CHARACTERIZATION OF LETTERKENNY AD
TNT WASHOUT WASTEWATER (30)

Parameter	Value
pH	5.9
TOC (mg/l)	200
SOC (mg/l)	140
Suspended Solids (mg/l)	230
COD (mg/l)	565
Total Solids (mg/l)	715
Oil/Grease (mg/l)	185
Alkalinity (mg/l as CaCO_3)	28
Acidity (mg/l as CaCO_3)	32
Chloride (mg/l)	50
TNT (mg/l)	146

TABLE 19. CHEMICAL CHARACTERIZATION OF LETTERKENNY AD
COMP B WASHOUT WASTEWATER (30)

Parameter	Value
pH	7.0
TOC (mg/l)	220
SOC (mg/l)	150
Suspended Solids (mg/l)	145
COD (mg/l)	625
Total Solids (mg/l)	515
Oil/Grease (mg/l)	136
Alkalinity (mg/l as CaCO_3)	48
Acidity (mg/l as CaCO_3)	8
Chloride (mg/l)	11
TNT (mg/l)	168

53,680 gallons. Washout utilizes 129 gpm. During operation fresh water must be added daily to make up evaporative losses. Makeup volume required during winter months was low, although 240 to 300 gallons of make upwater were required daily during summer months of operation. When the washout facility is re-activated, water discharged from the system will be monitored by collection of 24 hour composite samples to be analyzed for

TNT, pH, acidity, alkalinity, and total suspended and settleable solids (10). Washout facility reactivation is projected in support of the Prototype Depot Disposal System, with water-slurried explosive being provided to the fluidized bed incinerator from the washout facility.

e. Anniston Army Depot

(1) The Anniston AD washout facility is somewhat unusual, in that it has had a successful history of handling Comp-B explosives, and was scheduled to begin washout operation in late 1976 on Octol-loaded munitions, based upon the results of a recent trial run of 100 rounds. The present washout facility began operation in 1972, but has been on inactive status since 1974.

(2) The washout facility was to be reactivated for Octol-loaded munitions. The washout operation is intended to recover shells, but octol will not be recovered. A washout rate of 50 rounds/day is projected. Each round weighs eight pounds (including octol). A total of 12,000 rounds are programmed for washout. Washout of octol will be on a batch basis, since octol will not be recovered. Molten octol and water will be pumped from the washout tank and the slurry of water and explosive gravity clarified and otherwise conventionally treated for water reuse. Excess water for discharge is not anticipated as fresh makeup water is normally required to replace evaporative losses (111). Upon final cleanout of the recirculation system, at the conclusion of the octol work, the system water will be discharged into the plant's leaching pit. No data were provided on the characteristics of this wastewater. The octol will be burned.

f. Tooele Army Depot

(1) ~~The single wastewater source for demilitarization activities at Tooele Army Depot is a washout facility. This facility, installed in 1948, has not operated since 1960. During the period of active service, the washout facility processed munitions loaded with TNT, tritonal, amatol and Composition B. With the exception of amatol, all explosives were pelletized and recovered. The work level was not sufficient to justify recovery of amatol.~~

(2) The Tooele washout facility is of an older type than those at most Army Depots. It utilizes a partial water recycle process, but does not incorporate cooling coils, filtration or a

recycle reservoir. The system discharges 60 to 100 gpm of water, resulting from displacement of hot water by washed out explosive in the washout system. This discharge flows to baffled sedimentation sumps for evaporation and ultimate disposal by burning.

(3) During washout of Composition B, the system operated at a water temperature of 205°F in order to reduce the viscosity of the molten explosive and improve ease of handling. Otherwise, the system operated at 180°F. Once each week the system was drained of all water and cleaned up. No waste characterization data were provided on the washout effluent. However, design criteria developed by Tooele personnel for a prototype treatment system estimates a total wastewater volume of 30,000 gallons for treatment each time the washout facility is dewatered (30).

g. NWSC Crane

The washout facility at NWSC Crane differs from the standard Army process in that the Navy system operates at ambient temperature, but at pressures up to 9000 psi. The Army system operates at temperatures near 200°F, but at relatively low pressure (~90 psi). There are no wastewater characterization data on the NWSC Crane washout plant, since it had not yet been operated. Expected flow from the washout plant is 32 gpm. This will be discharged, after treatment as described in Section II of this chapter.

h. The limited data presented above concerning wastewater characteristics from washout operations are summarized in Table 20. The continuous flows (Table 20) associated with operations at Longhorn and Crane result from high pressure washout. The Tooele continuous flow originates from one of the older Army high temperature facilities. Although waste characterization data are extremely limited, the washout discharges contain significant quantities of TNT, oil, and suspended solids and can be presumed to be comparable to LAP wastewaters. (2)

67. STEAMOUT

In steamout facilities, steam is applied to the filled munition to cause the explosive or propellant to melt. Steam may be applied directly to the explosive or to the outside of the munition casing. Steamout facilities are also present at some Army Ammunition Plants. Several AAP steamout facilities were visited during a previous study on wastewaters of munitions

TABLE 20. SUMMARY OF WASHOUT WASTEWATER CHARACTERISTICS

Location	Discharge		Constituent Concentrations			
	Batch, gal	Continuous, gpm	pH	TNT, mg/l	TOC, mg/l	Susp. Solids, mg/l
Longhorn AAP	-	10 (each)	-	-	-	-
Savanna AD	38,000 (wk)	-	8.2	23	-	121
Letterkenny AD	18,000 ⁽¹⁾	-	5.9	146	200	230
	18,000 ⁽²⁾	-	7.0	168	220	145
Red River AD	53,680	-	-	-	-	-
Tooele AD	30,000	60-100	-	-	-	-
NWSC Crane	-	32	-	-	-	-

(1) Washout of TNT-filled items

(2) Washout of Composition B-filled items

manufacture (2). There are no steamout facilities at Army Depots (94). Despite the large number of steamout facilities (Table 21), waste characterization data are not available. Table 21 indicates military facilities having steamout capabilities (94).

a. NAD Hawthorne

Wastewater from the NAD Hawthorne Western Demilitarization Facility will result from use of hot water and low pressure steam in the meltout and washout/steamout building to remove explosives from their casings, and floor and equipment wash down and cleanup water. The bulk of the wastewater will result from the former activities. One estimate of the wastewater volume is 120-150 gpm from steamout/washout and up to 50 gpm from cleanup (106). The wastewater treatment plant, however, is sized for a flow of 400 gpm (113). This is probably in anticipation of an expanded role for the Western Demilitarization Facility in demilitarization of conventional munitions. The meltout/steamout facilities include equipment to process and recover the bulk and molten explosive, leaving an explosive-saturated wastewater (1). Since the facility is still under construction, waste characterization data are not yet available. Preliminary pilot wastewater treatability studies utilized hot water saturated with explosives. Characterization data for these "synthetic" wastewaters have been reported (106).

TABLE 21. MILITARY FACILITIES WITH STEAMOUT CAPABILITY (94).

Location	Direct Steam	Steam Cabinet
NWSC Crane	X	X
NAD Hawthorne	X	X
NAD McAlester	X	X
NWS Yorktown	X	
NTS Keyport	X	X
Joliet AAP	X	
Cornhusker AAP	X	
Newport AAP	X	
Pine Bluff Arsenal	X	

b. NWSC Crane

The steamout plant at NWSC Crane operates with a mixture of steam and water at a pressure of less than 15 psi. This facility

is used for large projectiles and bombs. The water is used on a once through basis and is partially lost through evaporation, with excess waste discharged through swamps to a creek. No waste characterization data were provided, although the water is hot and saturated with explosives, including TNT.

67. CHEMICAL CLEANING

Scrap metal derived from demilitarization operations must be cleansed of residual explosives prior to sale or reuse. Burning of combustible material and flashing of metal components at a burning ground or in a rotary demilitarization furnace are approved methods and have many applications. However, some operations require, for economic and technical reasons, that a chemical decontamination procedure be used. A decontamination solution containing 5% sodium sulfide and 10% sodium hydroxide, by weight, is used for items contaminated with TNT, Composition A-3, and Composition B. This solution was developed to be used to remove explosive films remaining from steamout/washout processes and is not adequate to remove large quantities of explosives. If the steamout/washout process does not reduce the explosive content to only a film, the use of a solvent wash or an additional steamout/washout operation may be required prior to the chemical decontamination. Normally the decontamination solution is made up in batch and dumped after its decontamination capacity is exhausted. The solution is maintained at a working temperature of 165 to 195°F, and each batch represents approximately 500 gallons of solution. A typical operation guideline requires discard of the solution after each 5,000 units of hardware are decontaminated. Following decontamination, each item is thoroughly rinsed with fresh water. Thus, two wastes are associated with the chemical decontamination process; the spent solution and the rinse water. NWS Crane has a chemical decontamination process. No waste characterization data were provided on either the cleaning solution or rinse water.

68. SCRUBBER WASTEWATER

a. General

Scrubber wastewater from demilitarization facilities results from air pollution abatement procedures. The quantities and environmental significance of this wastewater source will increase as the Military intensifies its air pollution control program. Air scrubber systems have been or are projected for installation on deactivation furnaces, propellant (powder)

conveyor systems, and similar activities resulting in air effluent particulates and gases. The use of water scrubbers to reduce air pollutant emissions to an acceptable level will result in contaminated scrubber water. Depending upon the method of discharge and/or treatment, the contaminated water might or might not result in pollution. General effects of water use for scrubber systems include: pH changes; increased solids; color; odor; temperature; toxicity; and decreased dissolved oxygen (94).

b. Sierra Army Depot

Sierra AD scrubber water results from a small-scale vacuum-type propellant recovery process. This yields a small volume of water, which has not been chemically characterized. The scrubber water is dumped into a burning pit, where water is lost by evaporation and percolation. Explosive residue in the pit is burned.

c. Letterkenny and Anniston Army Depots

Letterkenny AD and Anniston AD also employ powder collection system static wet scrubbers. The unit follows dry bag collectors. The wet scrubber contains a small volume of water (about 50 gallons). This water is not monitored. Weekly, at Letterkenny, the system is decanted and the water spread on the depot burning ground. After water loss by percolation and evaporation, the dried residue is burned. At Anniston, the scrubber water is also dispersed onto the burning ground.

d. NWSC Crane

NWSC Crane employs a marble bed scrubber (following a bag-house) on one demilitarization furnace. This scrubber is planned to be replaced with a venturi-type scrubber in order to achieve higher particulate control efficiency. The replacement venturi scrubber will utilize a recycle water system at 20 gpm. Present scrubber water is discharged to an open field, after a single use. This water, at 20 gpm, has the characteristics presented in Table 22.

e. Red River Army Depot

Red River AD plans to install venturi and packed tower scrubber air pollution controls on the Prototype Depot Disposal System proposed for installation at Red River. This system will

TABLE 22. NWSC CRANE SCRUBBER WATER CHARACTERISTICS (112)

Parameter	Concentration
pH	3.2-6.3
Total Dissolved Solids, mg/l	109-287
Suspended Solids, mg/l	0-108
Phosphorus, mg/l	0.03-0.36
Nitrate, mg/l	0.1-2.7
Sulfate, mg/l	50-107
Cyanide, mg/l	<0.1
Cadmium, mg/l	0.03-2.32
Copper, mg/l	0.02-2.40
Nickel, mg/l	<0.02
Lead, mg/l	0.05-19.1
Aluminum, mg/l	0.2-6.8

consist of three reaction units: fluidized bed reactor; confined detonation unit; and a decontamination oven. Scrubber wastewater volumes and other characteristics are not known at this time, although the venturi is expected to collect particles to the 0.1 micron size such as metallurgical fumes, zinc and magnesium oxides, and soluble gases. The packed tower scrubber removes dust, but is primarily intended for gaseous air pollutant absorption (10). It is anticipated that these scrubber waters will be partially recycled, although the extent of recycle is not known. Neither the type nor degree of wastewater treatment has been specified (115).

SECTION II

WASTEWATER TREATMENT AND DISPOSAL

69. INTRODUCTION

Most washout facilities employ similar processes of partial or complete wastewater treatment. The existing treatment facilities are discussed below. Additional paragraphs follow on: treatment of scrubber water; methods of effluent ultimate disposal; and economics of water pollution control.

70. WASHOUT TREATMENT FACILITIES

a. Savanna Army Depot

The Savanna AD wastewater treatment system was installed as an integral part of the APE 1300 washout facility in 1971, although an older washout facility also had wastewater treatment in the form of activated carbon beds installed in 1952. In the present system, wastewater is treated first in two gravity clarifiers. Clarifier supernatant is cooled by discharge over cooling coils, followed by diatomaceous earth filtration and discharge into a receiving reservoir. The filtered water in the reservoir is used for heat transfer in the cooling coils. Weekly, 38,000 gallons of reservoir water are treated by activated carbon and discharged into a leaching pit. The carbon system consists of fourteen 55-gallon barrels, each filled with granular activated carbon. The barrels are operated in parallel, in an upflow mode. Treated effluent discharges to a final reservoir prior to ultimate disposal. The total pumping rate through 14 barrels is 240 gpm. The carbon is changed once per month or more frequently, as required by visual inspection of the effluent. No chemical data were provided on the quality of the treated effluent.

b. Red River Army Depot

(1) The recycle water system of the Red River AD washout facility also incorporates treatment. After washout and gravity separation of the molten explosives, the water flows through gravity clarifiers, over cooling coils, through fiber filters, and finally through activated carbon beds. Sludge is withdrawn from the clarifier hoppers. The fiber filters are installed in risers of six trays each, with two banks of 48 trays per bank. Water percolates by gravity through the filter trays. The top two trays of each riser contain excelsior, the middle trays contain rubberized pad hair, and the bottom two trays contain fiberglass insulation-type filter pads. Pads are replaced as necessary, upon clogging.

(2) The filter effluent discharges into six parallel sunken granular activated carbon beds. The carbon is replaced as necessary - normally after 120 hours of operation. Batch carbon studies on Red River wastewater have been reported to reduce TNT from 4500 mg/l to 3 mg/l (124). These results are questionable, however, since the initial TNT level reported (4500 mg/l) far exceeds the solubility of TNT. TNT has a maximum solubility at 140°F of 675 mg/l.

(3) The treated water is either reused in the washout facility or discharged into a series of four evaporative ponds. These ponds, having a combined volume of 760,000 gallons, also receive surface runoff and septic tank effluents. Due to the high rainfall (49 inches per year), the lagoons frequently overflow into an adjacent creek (115). During summer, however, the lagoons may dry up. In the event that the washout facility is reactivated in support of the Prototype Depot Disposal System, excess washout water will be handled in the fluidized bed reactor.

c. Anniston Army Depot

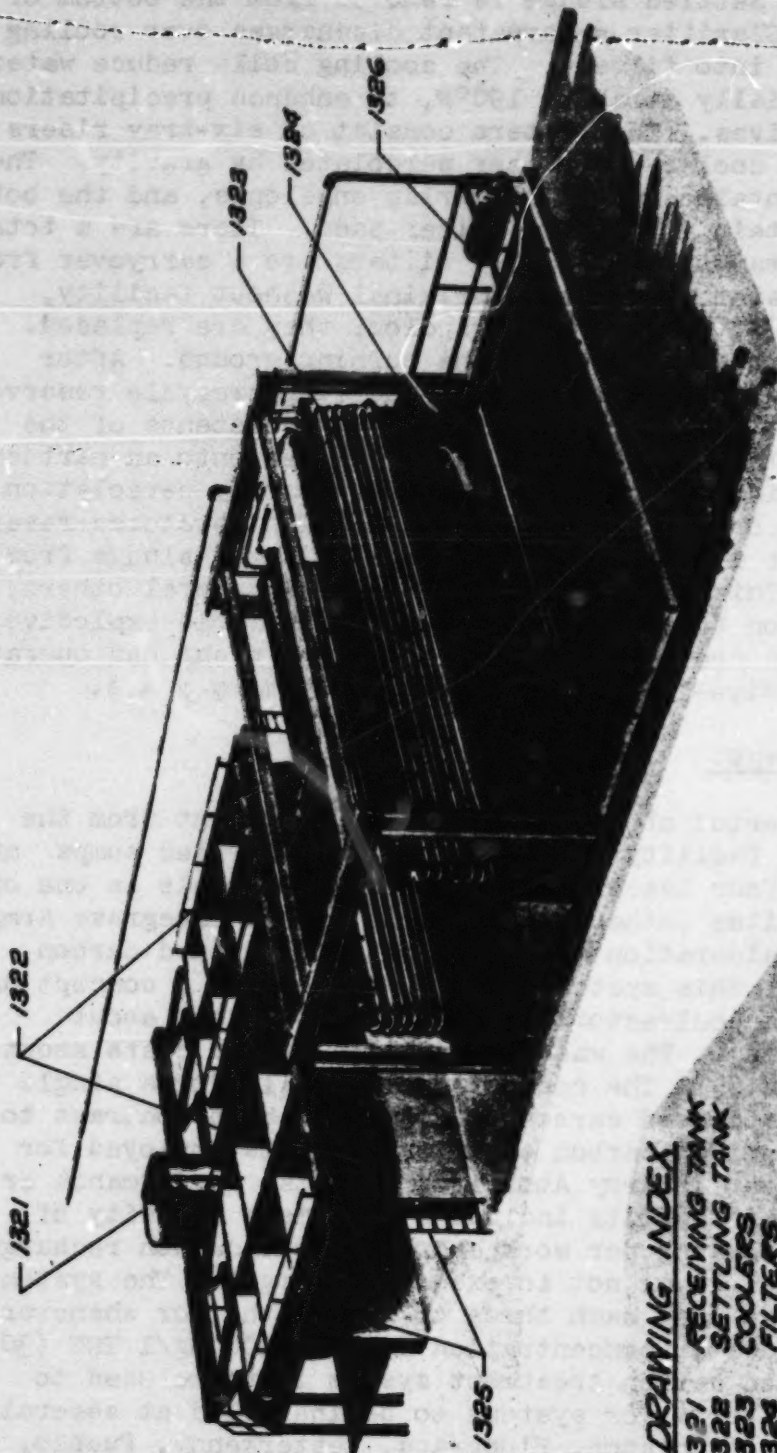
(1) The Anniston washout facility is typical, operating at 180-190°F and utilizing a recirculating water system. The water, after use, is gravity clarified, cooled by flow over cooling coils, and filtered in six-tray risers containing fiberglass, sawdust and other materials (Figure 12). The Anniston washout facility does not incorporate carbon treatment for the recycle water, and there are no immediate plans to install such a system (111).

(2) During the washout of Comp-B explosives, difficulties were encountered with clogging of the filters and caking of explosives on the cooling coils. It was often necessary to replace the filters on an hourly basis. This problem was partially alleviated by substituting a combination of fiberglass, sawdust and hemp thread fiber filters. An additional difficulty was the precipitation of Comp-B in the recirculating water reservoir. A stand-by reservoir was utilized during cleanout to dewater the sludge and allow the system reservoir to be mucked out. Excess water from the washout facility is pumped to a leaching bed. No data on wastewater volumes or other characteristics were provided.

(3) Other than treatment associated with the reuse of water in the washout facility, no additional treatment is projected by Anniston. Excess water is discharged to the leaching pit. It has been reported that this leaching pit can result in surface runoff into adjacent streams during periods of rainfall (111). When the pit dries up, residue is scraped from the pit and sent to the burning ground.

d. Letterkenny Army Depot

Treatment at the Letterkenny AD is limited to the recycling water of the washout facility. Explosive-laden water from the washout units flows into two parallel lines of two gravity



DRAWING INDEX

- 1321 RECEIVING TANK
- 1322 SETTLING TANK
- 1323 COOLERS
- 1324 FILTERS
- 1325 CATWALK & LADDERS
- 1326 PUMP, CENTRIFUGAL

**EXPLOSIVE WASHOUT PLANT
WATER RECLAMATION SYSTEM**

FIGURE 12 - APE 1300 Water Reclamation System. (130)

clarifiers each. Settled sludge is removed from the bottom of each clarifier. Clarifier supernatant discharges over cooling coils and spills into filters. The cooling coils reduce water temperature, initially at about 190°F, to enhance precipitation of soluble explosives. The filters consist of six-tray risers through which the cooled wastewater percolates by gravity. The top four trays contain sawdust in burlap envelopes, and the bottom two trays contain fiberglass filter pads. There are a total of 64 risers of trays. The sawdust filters are a carryover from the filtration system used in the original washout facility, constructed in 1972. As the filters clog, they are replaced. The clogged filters are burned at the burning ground. After filtration, the water discharges into the large recycle reservoir for reuse. When the system is dewatered, the contents of the reservoir (about 18,000 gallons) are discharged onto an earthen slope on the burning ground. The water is lost by percolation and evaporation. Dried residue is burned. The dewatered reservoir is mucked out and the sludge burned as is the sludge from the clarifiers. This washout facility, unlike several others, does not use carbon treatment for removal of soluble explosives during the recycle process. Despite this, the plant has operated safely with explosive-laden recycle water for many years.

e. Tooele Army Depot

During its period of active operation, effluent from the Tooele AD washout facility discharged through baffled sumps and into a series of four leaching pits. However, Tooele is one of three potential sites (others being Anniston and Bluegrass Army Depots) under consideration to test a pilot activated carbon treatment system. This system is to be based upon a concept design prepared by a contractor and estimated to cost about \$33,000 (1976 basis). The washout facility itself costs about \$600,000 (1974 basis). The concept design calls for a single column granular activated carbon unit. This is in contrast to the typical dual column carbon treatment systems employed for pink water treatment in Army Ammunition Plants. Performance criteria for the pilot facility include a treatment capacity of 29,000 gal of wastewater per work shift without carbon recharge and an effluent TNT level not to exceed 0.25 mg/l. The system is proposed for use once each three to six months, or whenever the recirculating water concentration exceeds 200 mg/l TNT (30). The pilot activated carbon treatment system is to be used to develop design criteria for systems to be installed at several washout facilities (Anniston, Bluegrass, Letterkenny, Pueblo, and Tooele Army Depots).

f. NAD Hawthorne

(1) NAD Hawthorne plans a more extensive type of treatment system for wastewater from the facility's meltout and washout/steamout operations. The plant will utilize a recycle water system, with zero liquid discharge. Efforts will be directed toward minimizing the volume of process water used at the facility (113).

(2) Process wastewater will flow to sumps located adjacent to each demilitarization building. This water will be collected by vacuum truck and transported to one of several (ultimately three) lined holding/evaporative ponds where the water will be retained to allow cooling. Some explosive will precipitate from the saturated wastewater as it cools, and the holding ponds will occasionally require dewatering for sludge removal.

(3) Effluent from the holding ponds will be pumped to the wastewater treatment plant, which will consist of the following sequence of treatment processes (106, 113):

1. Air Flotation
2. Mixed Media Filters
3. Carbon Adsorption Columns

The treated effluent will be recirculated for reuse in the demilitarization processes. Any excess water which cannot be reused will be evaporated. The net annual evaporation at Hawthorne is 55 inches per year. The evaporative pond system has been designed with sufficient capacity to handle all wastewater, in the event that the treated effluent could not be reused. Design criteria for the wastewater treatment system include a specification for 1.0 or less mg/l of all explosives present in the treated effluent. Since there is zero discharge, this effluent limitation was based upon internal process criteria to avoid build-up of explosives to hazardous levels (113). The effluent from the treatment facility is to be monitored by grab sampling and analysis for selected parameters, which have not yet been specified (113).

(4) Due to the present lack of capability to regenerate spent carbon, the activated carbon will be incinerated when its capacity is exhausted. The carbon, plus wastewater treatment plant sludges, will be incinerated in the Bulk Incinerator Facility. The carbon columns are designed for up-flow operation and plumbed for both parallel and series operation. They will

initially be operated in parallel, with one on-line and the second off-line to be recharged with carbon.

(5) The design treatment system has been pilot-tested with synthetic wastewater (106). Performance results indicated that the effluent criteria of 1 mg/l can be met for TNT, ammonium picrate and RDX, the explosives monitored in the pilot studies.

(6) Activated carbon is widely used for treatment of munitions manufacture and LAP wastewaters (2), as well as demilitarization washout effluents as described above. Carbon filters provide exceptionally effective treatment for dissolved TNT, as well as other explosive constituents. One major disadvantage is the present lack of capability to regenerate the spent carbon for reuse. Due to this lack of regeneration capability, alternative methods have been considered either to reduce the carbon usage or to provide a substitute for activated carbon treatment.

72. ALTERNATIVE TREATMENT

a. Rocky Mountain Arsenal

Pilot treatment work associated with the DOD Installation Restoration Program at Rocky Mountain Arsenal has potential application for washout demilitarization wastewaters. The pilot unit under investigation is a gravity flow carbon coagulation bed system. Other processes under consideration by Picatinny include ozonation treatment, microfiltration and membrane separation processes. Depending upon the results of studies at Rocky Mountain and Picatinny Arsenals these processes may have application in conventional munitions demilitarization activities.

b. Polymeric Resin

One substitute for activated carbon is use of polymeric resin columns. The resin adsorbs pollutants and can be regenerated by use of appropriate solvents. This type of system is planned for the washout effluent at NWSC Crane.

c. NWSC Crane

(1) The Crane high-pressure washout facility has a clarifier plus filtration system for suspended solids. Current plans are to add a polymeric resin system, of the type investigated in pilot studies at NAD Hawthorne (106), for removal of dissolved explosive. The resin system will require chemical regeneration,

resulting in a regenerant brine for final disposal. The present high-pressure washout facility (two washouts in series with a common water system), uses a hydrosieve for explosive solids separation. The water then flows through a clarifier, basket (cartridge-type) filter, and to a clear well for reuse. Sludge from the clarifier will be either burned or placed into permanent plastic containers and landfilled. The resin system will be installed later, if necessary, to control soluble explosive levels in the recycle water.

(2) The polymeric resin proposed for use is Amberlite XAD-4. This material is a cross-linked polystyrene polymer. The adsorption columns are intended to operate at 1 gal/min/ft³ (8 BV/hr). Table 23 presents adsorption capacity data for XAD-4. Table 24 presents the test raw waste stream characteristics. Acetone will be used as the resin regenerant. The acetone will be recovered for reuse by live steam-tray distillation.

TABLE 23. ADSORPTION CAPACITY FOR XAD-4 (1)

Explosive	Resin Capacity, [*] lb/ft ³
TNT	6.98
HMX	0.084
RDX	0.076

* Capacity at 1 mg/l explosive leakage in effluent

TABLE 24. WASTEWATER CHARACTERISTICS (1)

Parameter	Concentration
pH	7.5
TNT, mg/l	140
HMX, mg/l	10

(3) Two new treatment systems proposed for LAP activities at NWSC Crane have potential application to demilitarization wastewaters. One, located near the steamout facility, is a recycle water system at the Bomb Fill Plant. This system filters particulate explosive from air pollution scrubber water used in the melt-pour operation. The filtered water is recycled and sludge is burned. The second system is the TNT treatment facility associated with LAP of Rockeye munitions. This treatment system, scheduled for construction in late 1976 or early 1977, involves water chilling to enhance precipitation of soluble explosive, followed by disposable cloth belt filters and carbon column treatment. Flow will be 40-50 gpm. This flow volume is reported to be the breakpoint on economics between use of polymeric resin (for higher flows) and carbon (for lower flows). Performance criteria include reduction of TNT from levels of 150-250 mg/l down to 0.5 mg/l to allow water recycle. The carbon system will involve two packed bed gravity downflow columns in series with one additional column on standby. Spent carbon will be incinerated in the rotary furnaces. Anticipated carbon use is 3000 lb/year, based on a wastewater TNT content of 150 mg/l.

72. SCRUBBER WASTEWATER

a. The Army has limited experience with treatment of air pollution scrubber water, because of the limited number of air pollution scrubbers currently installed. At Red River AD, treatment is projected to be required for excess water from the venturi and packed tower scrubbers planned for installation on the Prototype Depot Disposal System. Type and extent of treatment required has not been determined, however.

b. Treatment is also planned for the wastewaters of the venturi scrubber recycle system on the demilitarization furnace at NWSC Crane. The recycle scrubber water will be neutralized with caustic to pH 7 to reduce wastewater constituent concentrations and allow continuous water reuse without blowdown. Laboratory tests on pH adjustment treatment of the scrubber waste resulted in the following results at pH 8.5:

<u>Parameter</u>	<u>Concentration, mg/l</u>	
	<u>Initial</u>	<u>Final</u>
Cadmium	0.40	0.05
Copper	1.64	0.02
Iron	1.62	0.08
Lead	14.2	0.08
	102	

Treatment at higher pH, up to 10.0, resulted in improved removal of cadmium, but reduced treatment efficiency for the other metals. After pH adjustment treatment, the sludge will be removed to landfill without dewatering, and the water reused in the venturi scrubber system. Anticipated flow is 10 gpm.

73. ULTIMATE EFFLUENT DISPOSAL

The environmental significance of the method of ultimate effluent disposal depends in large measure upon: demilitarization process; the degree of treatment provided prior to disposal; as well as the disposal method itself. Table 25 summarizes methods of ultimate disposal discussed above for washout effluents. With the exception of NAD Hawthorne, all facilities described in Table 25 discharge effluents with some potential to contaminate ground and/or surface water. This potential has been cited in the case of Pueblo AD during a wastewater survey (54). Table 26 lists additional demilitarization facilities and presents associated ultimate disposal methods.

TABLE 25. ULTIMATE DISPOSAL METHODS FOR WASHOUT EFFLUENTS

Location	Disposal
Savanna AD	Leaching pit, after activated carbon treatment.
Red River AD	Unlined evaporative ponds, after activated carbon treatment (some overflow). Future excess water to be evaporated in fluidized bed incinerator.
Anniston AD	Leaching pit after filtration. Some overflow.
Letterkenny AD	Land overflow after filtration.
Tooele AD	Leaching pits after sedimentation..
NAD Hawthorne	Complete recycle; zero discharge. Lined evaporation ponds.

TABLE 26. DEMILITARIZATION FACILITIES ULTIMATE DISPOSAL METHODS

Location	Disposal	Reference
Pueblo	Leaching pit	54
Bluegrass AD	Leaching pit (present)	45
	Lined pond (future)	43
Umatilla AD	Evaporative Pond	74

74. ECONOMICS OF WATER POLLUTION CONTROL

Limited economic data are available on pollution control technologies described in this chapter. These data are summarized in Table 27. Figure 13 compares capital and operating costs for activated carbon versus polymeric resin treatment. The comparison indicates that at flows above 40 gpm, the resin system has an economic advantage for explosives wastewater treatment.

76. PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

The APE 1300 hot water washout system is the only major demilitarization process with potential for water pollution (pink water), and the degree of potential pollution varies with the terrain and climatology of the facility. Development programs encompassing carbon column and polymeric resin treatment, under investigation by several Army and Navy organizations, will provide effective treatment technology if adequately funded and properly designed. In addition, new processes are under investigation which involve pretreatment for removal of suspended solids, as well as total dissolved solids. These would permit significant opportunities for water re-use. High pressure and cavitating cold water washout are also alternatives with potential advantages for energy savings. Continued evaluation of alternative options is recommended.

TABLE 27. ECONOMICS OF DEMILITARIZATION WATER POLLUTION CONTROL

Wastewater Source	Capital Cost, \$1000	Operating Cost, \$/yr	Comments	Reference
Spent Chemical Decontamination Solution	10	-		1
Explosive Steamout	80	-		1
Hot Water Washout	120	-		1
Hot Water Washout	608	-	Carbon Treatment at 63 gpm.	30
High Pressure Washout	35-120	-		1
High Pressure Washout	832	122,000	Resin Treatment at 80 gpm.	1
High Pressure Washout	750	306,000	Carbon Treatment at 80 gpm.	1
High Pressure Washout	900	132,800	Carbon-Resin Treatment at 80 gpm.	30

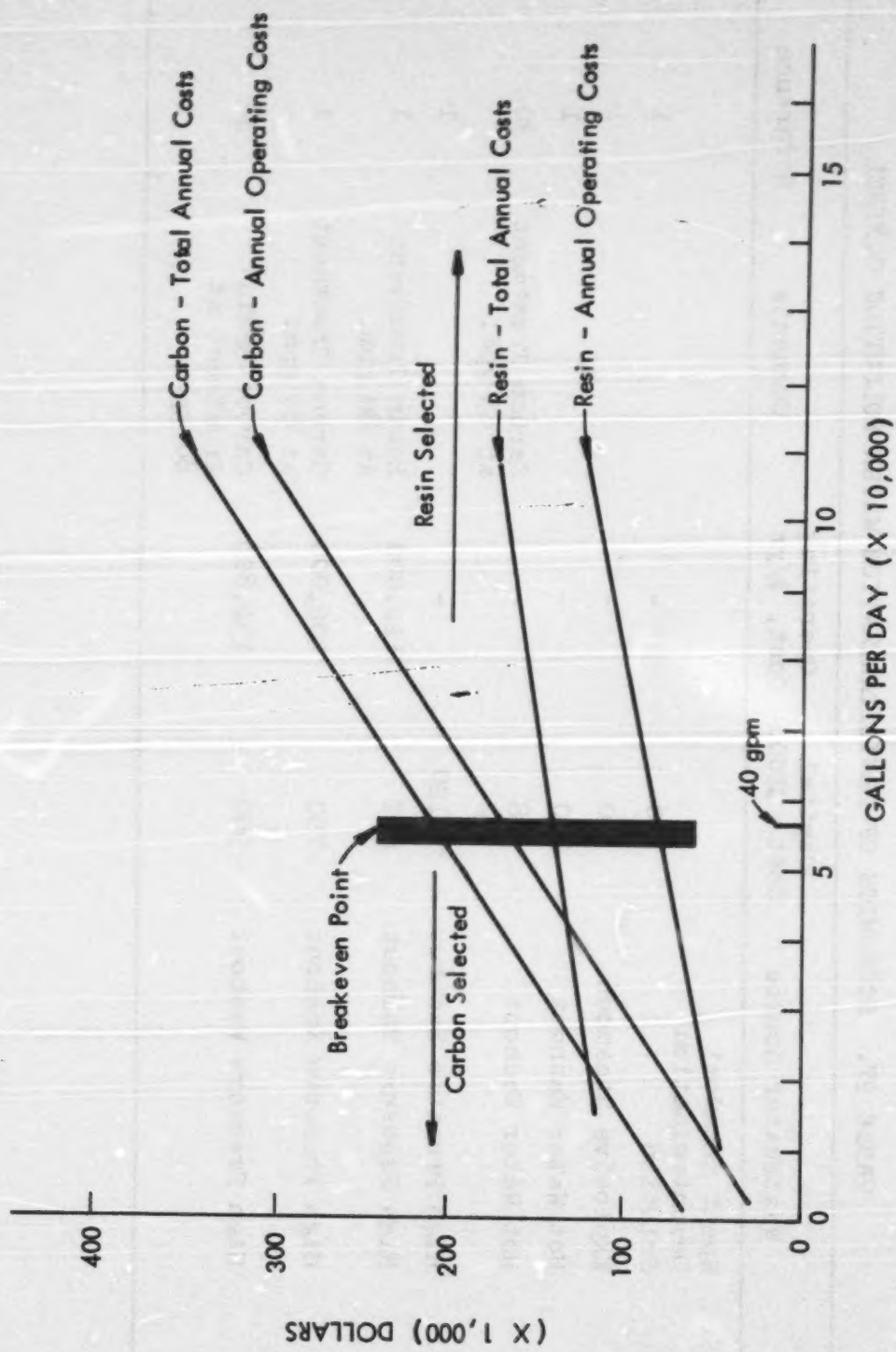


Figure 13 - Basic Selection Chart Carbon Vs. Resin. (126)

CHAPTER V

SOLID WASTES

77. INTRODUCTION

The issues of solid waste volumes generated, acceptable methods of disposal, and immediate and long term environmental impacts have not been addressed in a quantitative fashion by the demilitarization industry. Aspects of solid waste from demilitarization activities are presented below, on a facility-by-facility basis.

78. NWSC CRANE

Solid wastes associated with demilitarization activities result from: incineration of explosive-contaminated sludges and other solids (e.g., spent activated carbon); and from wastewater treatment sludge from the recycle marble bed scrubber on the rotary demilitarization furnace as well as ash collected in the baghouse on that furnace. These wastes have not been characterized. Ash from the baghouse is disposed to a landfill. Sludge from the recycle water system on the marble bed scrubber, which will ultimately be replaced by a venturi scrubber, is disposed without dewatering to landfill. Wastewater treatment data presented in the previous section of this report indicate that this sludge is concentrated in toxic metals. An additional sludge which may be disposed directly to landfill is the explosive sludge filtered from the recycle water in the washout plant. This sludge, collected from the clarifier, may be either incinerated or placed into containers and landfilled.

79. NAD HAWTHORNE

Solid wastes will result as ash from: incineration of explosive-contaminated sludges and other solids (e.g., spent activated carbon); from baghouse control devices; and as ash from coal combustion in the steam plant. The volumes and characteristics of these solids have not been defined. Most ash will

originate from the coal-fired steam boilers, with significant quantities also anticipated from the baghouses. From the coal to be utilized, coal combustion is expected to yield 15-40 percent ash. Only small quantities of ash are projected for the incinerators. Current expectation is that all ash will be disposed to a nearby municipal refuse landfill. This includes both incinerator and baghouse ash. Bulk explosives are to be incinerated in two rotary kilns, fed as a water slurry. The water to explosive ratio is 3:1. Potable water will be used to slurry the explosive. Each kiln has a capacity of 550 lb explosive/hour.

80. ANNISTON AD

Solid wastes result as sludges and as clogged filters from the washout plant, and dried residue from the leaching pit. These materials are burned at the burning ground. Solid wastes also result from operation of the deactivation furnace. Currently metal scrap is magnetically segregated at the small items furnace and recovered for sale. A baghouse is planned for particulate air pollution control on the deactivation furnace. This baghouse will collect ash, although the volume of ash has not been determined. No decision has been made on the disposal of this ash. Landfill disposal is under consideration.

81. LETTERKENNY AD

Solid wastes associated with demilitarization activities result as sludge and other residues from the washout facility and will result from particulate collection upon installation of a baghouse at the deactivation furnace. The washout facility residues are open burned at the burning ground. The baghouse is projected to collect 90 pounds per hour of ash (design criteria), totalling 400 to 600 pounds per day. At the time of this plant visit, the method of ultimate disposal of the ash has not been designated. A USGS survey has indicated that geological conditions at the Depot are not suitable for landfill, and an alternate ultimate disposal method for the baghouse ash must be determined. Metal scrap also originates from the deactivation furnace operation. This scrap is magnetically segregated, recovered and sold. The brass scrap in particular has high resale value.

82. RED RIVER AD

Solid wastes associated with demilitarization result as sludges, clogged filter pads and spent carbon from the washout

facility, plus solids resulting from use of the deactivation furnaces. The washout facility residues are open-burned. Metal residues from deactivation furnaces are recovered as scrap. Three deactivation furnaces are programmed for baghouse installation. These baghouses will collect ash residue, which will be disposed by landfill.

83. SAVANNA AD

Solid wastes are associated with the washout facility in the form of clarifier sludge, spent diatomaceous earth filter, and spent activated carbon. These materials are open burned. Dried residue from the leaching pit is collected by scraping and also burned. Other solid wastes result from the deactivation furnace. Brass residue is collected for sale. A baghouse, to be installed at the deactivation furnace for air pollution control, will collect ash, which will be landfilled. Non-explosive contaminated solid waste associated with demilitarization activities is also landfilled.

84. SIERRA AD

Solid wastes at the plant result from the deactivation furnace and demolition grounds as scrap metal and as ash from the coal-fired steam boiler. The scrap metal from the deactivation furnace is magnetically segregated, and all scrap metal is sold as scrap. The ash is piled on land and applied to roads on the depot during the winter. Current plans are to install a baghouse on the deactivation furnace exhaust stack. Ash from the baghouse is to be landfilled on the depot property. Bulk explosives and explosive-contaminated solid wastes are disposed of by open burning at the depot.

85. TOOELE AD

Solid wastes result from the washout facility and from air pollution control devices on the deactivation furnace. Washout facility wastes include sludges from the discharge sumps and dried residue from the leaching beds receiving the sump overflows. These wastes are collected and open burned. Deactivation furnace residues result from a cyclone separator and a baghouse. The cyclone collects larger particles (>5 micron), which are primarily unburned carbon residues. The baghouse collects micron and sub-micron particles, mainly metal oxides. Tables 28 and 29 present characterization data on samples collected from the

TABLE 28. CHARACTERIZATION OF CYCLONE DUST SAMPLES (131)

Demilitarized Item	Percent Combustibles (500°C)	Metal Content, Percent			
		Lead	Magnesium	Strontium	Barium Potassium
Cartridges, 30 mm Tracer	0.9-2.4	24.3-29.7	8.9-9.9	14.7-16.4	1.3-7.2
Booster, M 21A4	14.3-46.5	8.0-18.4			
Fuse, Base Detonating M 66A2	9.5	15.6			
Primer, Percussion M 28B2	5.9-9.7				0.8-1.2
Bulk TNT	22.3				
Range	0.9-46.5	8.0-29.7	8.9-9.9	14.7-16.4	1.3-7.2 0.8-1.2

TABLE 29. CHARACTERIZATION OF BAGHOUSE DUST SAMPLES (131)

Demilitarized Item	Percent Combustibles (500°C)	Metal Content, Percent			Other
		Lead	Magnesium	Strontium	Barium
Cartridge, 30 mm Tracer	3.3-4.2	19.0-32.1	4.2-10.6	4.4-8.8	0.4-4.6
Cartridge, 50 mm Tracer	11.4	30.2	12.7	7.3	1.8
Cartridge, 50 APIM8	2.1	24.9	3.2		1.6
Booster, M21A4	8.9-68.1	1.6-18.4			0.2(Calcium) 3.5(Aluminum)
Primer, Percussion M28B2	5.4				7.1-16.1 (Aluminum)
Bulk TNT	10.4-41.1				1.2(Potassium)
Range	2.1-68.1	1.6-32.1	3.2-12.7	4.4-8.8	0.4-4.6

cyclone and baghouse. Currently, air pollution control device residues are burned in a burning pit. However, disposal to landfill is under consideration.

86. PRELIMINARY CONCLUSIONS

Additional study is needed to determine whether solid wastes from demilitarization constitute an environmental problem, and, if so, to what degree.

REFERENCES

AMERICAN DEFENSE PREPAREDNESS ASSOCIATION (ADPA)

1. Proceedings, "Symposium on Demilitarization of Conventional Munitions," ADPA, NAD Hawthorne, Nevada, 20-22 April 1976.
2. "Wastewater Treatment in the Military Explosives and Propellants Production Industry," ADPA, October 1975.

AIR FORCE

3. "Burners for Disposal of Rocket Propellants," AF RPL-TR-76-2, John Denker, Air Force Rocket Propulsion Laboratory, Edwards AFB, June 1976.

ARMY - U. S. ARMY ARMAMENT COMMAND

4. Hq. US ARMCOM Letter AMSAR-ISE, dated 4 August 1975, Subject: "Open Air Burning of Explosives and Explosive Contaminated Wastes."
5. "Ammunition Explosives Washout and Reclamation System, APE 1300," USA ARMCOM, 1 February 1974.

ARMY - U. S. ARMY DEPOTS

Anniston Army Depot

6. "Current Capabilities for Disposal of Ammunition," Anniston Army Depot, Anniston, Alabama, June 1976.
7. "SOP for Demilitarization of 30 and 50 Caliber Cartridges."
8. "SOP for Burning of Loaded Projectiles and Mines."
9. "SOP for Detonation of High Explosive Loaded Items."

Red River Army Depot

10. "Demilitarization of Conventional Explosives, Propellants and Munitions at Red River Army Depot," 15 July 1976, Red River Army Depot.
11. "Standing Operating Procedure - Demilitarization - Destruction by Demolition of Explosives, Ammunition, Loaded Components and Pyrotechnics," Red River Army Depot, Texarkana, Texas, SOP Nr. AMXRR118, Revised 7 October 1975.
12. "Standing Operating Procedure - Demilitarization of Explosive Loaded Ammunition Items by Washout (TNT)," Red River Army Depot, Texarkana, Texas, SOP Nr. AMXRR-204, Revised 5 February 1973.

Savanna Army Depot

13. "Standing Operating Procedure - Destruction by Burning of Explosive and All Related Compounds," Savanna Army Depot, Savanna, Illinois, SOP Nr. SVAD-23-65, Revised 8 September 1975.
14. "Standing Operating Procedure - Destruction by Demolition of Explosives Ammunition, Loaded Compounds and Pyrotechnics," Savanna Army Depot, Savanna, Illinois, SOP Nr. SVAD-22-65, Revised 2 June 1970.
15. "Standing Operating Procedure - Disposal of Ammunition by Processing in the Deactivation Furnace," Savanna Army Depot, Savanna, Illinois, SOP Nr. SVAD-10-61, Revised 18 July 1975.
16. "Standing Operating Procedure - (Washout) - Projectiles, All Sizes, Loaded with Comp B, TNT or Tritonal Explosives," Savanna Army Depot, Savanna, Illinois, SOP Nr. ST-MT-10-71, Revised 9 December 1971.
17. Hq. U. S. Army AMC Environmental Impact Assessment, "Open Burning of Ammunition, Savanna Army Depot," dated 17 July 1975.
18. Savanna Army Depot Letter AMXSV-DF, Subject: "Open Air Burning of Explosives and Explosive Contaminated Wastes," dated 25 July 1975.

19. Savanna Army Depot MFR, Subject: "Open Air Burning," dated ~~21~~ March 1976.
20. Savanna Army Depot Letter, AMXSV-DF, Subject: "Annual Status Report on Environmental Programs and Activities, RCS-DD-H&E(A)-1269," dated 21 January 1976, with Encl.
21. DA AMC Environmental Impact Assessment, "Installation Operations - Savanna Army Depot," dated 17 September 1975.
22. Internal Memorandum, Savanna AD, dated 29 February 1972.
23. Internal Memorandum, Savanna AD, dated 29 September 1961.
24. Savanna Army Depot Letter AMXSV-DF to Illinois Environmental Protection Agency, dated 29 May 1975.

Tooele Army Depot

25. Tooele Army Depot Letter AMXTE-AEO, Subject: "Air Pollution Control System for APE 1236 Deactivation Furnace," dated 29 April 1975.
26. "Pollution from Open Air Detonation and Open Burning," December 1972 by R. W. Hayes, Tooele Army Depot.
27. "Purchase Description for Fabric Filter System for APE 1276," January 1976, Tooele Army Depot.
28. "APE 1276 Air Pollution Control System for APE 1236 Deactivation Furnace," Ammunition Equip. Office, Tooele Army Depot, 29 April 1975, AMX TE-AEO.
29. "Thermo Chemistry Computer Predictions for Air Pollution from Combustion," Ralph Hayes, Ammunition Equipment Office, Tooele Army Depot, August 1973.
30. "Explosive Waste Water Treatment System for APE 1300 Washout Plant, Final Report," AEO, Tooele Army Depot, July, 1976, Report Nr. AEO-46-76.
31. Letter from Tay Can Scientific and Engineering Services, to AEO, Tooele Army Depot, dated 22 June 1976.

32. "APE 1276 Pilot Model Air Pollution Control System for APE 1236 Deactivation Furnace," Test Report, Daniel B. Hill, Report AEO-052-76, Tooele Army Depot, July 1976.
33. "Final Report, Air Blast Wave Damage Minimization by Explosive Charge Burial Depth for Tooele Army Depot," June 1976.
34. "Summary Report, Pollution from Open Air Detonation and Open Burning," December 1972.
35. "Ammunition Disposal Capabilities, Tooele Army Depot."
- 35a. Tooele Army Depot Letter DRXTE-AEO, subject: "Final Draft, Preliminary Assessment Report, Demilitarization of Conventional Munitions," dated 3 June 1977.

ARMY - U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY

Ambient Air Monitoring Networks

36. 21-031-72/74, Ambient Air Monitoring Networks Survey, 2 October 1973.
37. 21-008-74/76, Air Pollution Engr. Special Study, Ambient Air Quality Instrument Study, 23 May-28 July 1975.

Anniston Army Depot

38. 24-032-75, Water Quality Monitoring Consultation, 21-25 October 1975 - Completed 18 April 1975.
39. 21-033-74/76, Air Pollution Engr. Special Study - Management of Ambient Air Monitoring Networks, June 1975 - Completed 12 September 1975.
40. 24-018-75, Water Quality Engr. Survey - Completed 13 December 1974.
41. 21-007-73, Air Pollution Engr. General Survey, 11-12 December 1972 - Completed 15 March 1973.

Fort Wingate

42. 21-033-74/76, Air Pollution Engr. Special Study, Management of Ambient Air Monitoring Networks, June 1975 - Completed 12 September 1975.

Lexington-Blue Grass Army Depot

- 43. 24-006-74/75, Water Quality Engineering Special Study, 29 October-16 November 1973, 15-19 April 1974 - Completed 21 July 1975.
- 44. 24-058-74/75, Water Quality Monitoring Consultation, 15-19 April 1974 - Completed 17 December 1974.
- 45. 24-025-71/72, Water Quality Engineering Survey, 24-28 May 1971 - Completed 20 October-1971.
- 46. 21-007-71, Preliminary Air Pollution Engineering Survey, 5-7 October 1970 - Completed 5 January 1971.

Navajo Depot Activity

- 47. EHES Report, General Sanitary Engr. Survey, 8-9 May 1973.

Red River Army Depot

- 48. 24-030-74/76, Water Quality Engineering Special Study, Industrial and Domestic Wastewaters, 3-21 June 1974 - Completed 14 November 1975.
- 49. 21-H05-75, Air Pollution Engr. Survey, 28-30 April 1975 - Completed 8 September 1975.
- 50. 24-076-74/75, Water Quality Monitoring Consultation, 10-14 June 1974 - Completed 23 December 1974.

Pueblo Army Depot

- 51. 24-010-75/76, Water Quality Geohydrologic Consultation, 30 September-4 October 1974 - Completed 6 August 1975.
- 52. 24-019-75/76, Water Quality Biological Study, Preliminary Biological Evaluation of Surface Waters, 30 September 1974-1 May 1975 - Completed 18 July 1975.
- 53. 24-067-74/75, Water Quality Monitoring Consultation, 13-24 May 1974 - Completed 10 February 1975.
- 54. 24-068-74/75, Results of Wastewater Survey Incident of TNT Washout Facility, Bldg. AWS-6, 19 March 1974 - Completed 6 December 1974.

55. EHES Report, Water Pollution Monitoring Program Survey, 27 February-2 March 1973.
56. EHES Report, Solid Waste Survey, 26 February-2 March 1973.
57. 21-011-73, Air Pollution Engr. Source Sampling Survey, 27 November-2 December 1972 - Completed 25 April 1973.

Savanna Army Depot

58. EHES Report, Water Quality Engr. General Survey No. W52-74, 5-9 November 1973.
59. ~~24-022-74~~, Preliminary Report, Water Quality Engr. Survey, 5-9 November 1973 - Completed 1 August 1974.
60. 24-023-74, Water Quality Monitoring Consultation, 3-5 December 1973 - Completed 30 August 1974.
61. 21-008-72, Preliminary Air Pollution Engr. Survey, 12-13 October 1971 - Completed 5 January 1972.

Seneca Army Depot

62. 26-006-76, Solid Waste Survey, 29 September-1 October 1975 - Completed 8 December 1975.
63. 24-024-74, Water Quality Monitoring Consultation, 11-14 November 1973 - Completed 22 February 1974.
64. 24-023-71, Water Quality Engr. Survey, 26-30 April 1971 - Completed 23 August 1971.
65. 21-013-71, Preliminary Air Pollution Engr. Survey, 16-18 November 1970 - Completed 2 February 1971.

Sierra Army Depot

66. 21-010-75, Results of Consultation Visit Made on 29 April-1 May 1975 - Completed 16 June 1975.
67. EHES Report, Air Pollution Engr. General Survey, Sierra AD, 28-30 May 1974.
68. 24-015-75, Water Quality Monitoring Consultation, 17 September 1974 - Completed 11 November 1974.

Tooele Army Depot

- 69. 21-001-73, Air Pollution Engr. General Survey, 11-13 September 1972 - Completed 11 January 1973.
- 70. 24-013-75, Water Quality Monitoring Consultation, 9-11 September 1974 - Completed 14 April 1975.
- 71. 24-052-75/76, Water Quality Geohydrologic Consultation, 16-20 June 1975 - Completed 10 October 1975.
- 72. 21-014-75/76, Air Pollution Engr. Source Study, APE 1236 Deactivation Furnace, 30 July-12 August 1975 and 6-10 October 1975 - Completed 18 December 1975.

Umatilla Army Depot

- 73. EHES Report, Preliminary Air Pollution Engr. Survey, 29 April-2 May 1974.
- 74. 24-014-75, Water Quality Monitoring Consultation, 12-13 September 1973 - Completed 14 November 1974.
- 75. EHES Report, Sanitary Engr. Special Study Wastewater Treatment Facility, 24-31 October 1972.

ARMY - DARCOM (U. S. ARMY MATERIEL DEVELOPMENT AND
READINESS COMMAND) (FORMERLY "AMC")

- 76. AMC Pamphlet AMCP 700-3-1, "Complete Round Charts, Propellant Actuated Devices," December 1973.
- 77. AMC Pamphlet AMCP 700-3-2, "Complete Round Charts, Ammunition Through 20mm," December 1973.
- 78. AMC Pamphlet AMCP 700-3-3, "Complete Round Charts, Artillery Ammunition and Fuzes," May 1975.
- 79. AMC Pamphlet AMCP 700-3-5, "Complete Round Charts, Grenades, Mines, Pyrotechnics, Rockets, Rocket Motors, Demolition Material," May 1975.

ARMY - DARCOM AMMUNITION CENTER

80. "AMC Depot Disposal System - Project Report EV 15-73," U. S. Army Materiel Command Ammunition Center, Savanna, Illinois, 19 July 1973 (Rev. 1 February 1974).

ARMY - ENGINEERS CORPS

81. "Concept Design Analysis - WPC Monitoring Station Project 972.100, FY 74 Savanna Army Depot, Illinois," U. S. Army Corps of Engineers District, Omaha, Nebraska, April 1975.

ARMY - PICATINNY ARSENAL

82. "Evaluation of an Incinerator for Waste Propellants and Explosives," Tech. Report 4984, Rolison, Dickenson and Scola, Picatinny Arsenal, Dover, N. J., December 1976.
83. "Operation and Maintenance Manual Deactivation Furnace, APE 1236," USA MUCOM, 9 December 1970, Picatinny Arsenal, N. J.
84. "Development of a Fluidized Bed Incinerator for Explosives and Propellants," October 1973, C. D. Kalfadelis, Picatinny Arsenal.
85. "Design Guide for Propellant and Explosive Waste Incineration," October 1973, J. Santos, Picatinny Arsenal.

ARMY, HEADQUARTERS, DEPARTMENT OF

86. "Army Equipment Data Sheets, Ammunition Peculiar Equipment," TM 43-0001-47, Hq. DA, Washington, D. C., July 1975.
87. "Open Burning of Waste Munitions," Memorandum for Deputy Assistant Secretary of the Army, 12 April 1976.

DEPARTMENT OF DEFENSE

88. "Memorandum on Open Burning," Assistant Secretary of Defense, 1976.

ENVIRONMENTAL PROTECTION AGENCY

89. U. S. EPA Region V/Savanna Army Depot Consent Declaration, dated 28 November 1975.
90. U. S. EPA Region V Letter to Illinois Environmental Protection Agency, dated 25 February 1975.
91. U. S. EPA Region V Letter to Savanna Army Depot, dated 20 May 1975.

ILLINOIS, STATE OF

92. Illinois Environmental Protection Agency Letter to Savanna Army Depot, dated 7 May 1975.
93. Illinois Environmental Protection Agency NW Regional Office Letter to Savanna Army Depot, dated 19 September 1975, with Savanna Army Depot reply, dated 24 September 1975.

JOINT CONVENTIONAL AMMUNITION PROGRAM COORDINATING GROUP

94. "Final Report of the Joint AMC/NMC/AFLC/AFSC Commanders' Panel on Disposal Ashore of Ammunition," Vol. I-III incl., 7 March 1973.
95. "Joint Conventional Ammunition Demilitarization and Disposal Report on Conventional Ammunition Demilitarization and Disposal Research, Development, Engineering and Modernization Data Base," 15 January 1975.
96. "Demilitarization/Disposal Handbook, Volume I & II, Demilitarization/Disposal Inventory," JCAP, Rock Island, Ill., 31 December 1975.
97. "Conventional Ammunition Demilitarization/Disposal Technology Handbook," JCAP, Rock Island, Ill., May 1976.
98. "Conventional Ammunition Demilitarization and Disposal Technology Handbook," JCAP, Rock Island, Ill., November 1976.

NAVY - CRANE NWSC

99. Technical Report - AEDA Box Incinerator, U. S. Naval Ammunition Production Engineering Center, Crane, Indiana, June 1975.
100. NWSC Crane, "Processes for Explosives Removal from Explosives Loaded Ammunition."
101. NWSC Crane, "Process Design for the Removal of Nitro bodies from the Wastewater of Munitions Plants."
102. Standard Operating Procedures:
 - a. SOP, Breakdown of 3" Cartridges
 - b. SOP, Removal of Explosive TNT Sample from MK8 Depth Charge
 - c. SOP, Demil of MK8 & 9 Depth Charge and Flake Package TNT
 - d. SOP, Demil of MK82, 82 GP Bombs, Pellet, Package H-6, TRIT Explosive
 - e. SOP, General Furnace Demilitarization Operations
 - f. SOP, Demilitarization of .50 Caliber Cartridges, all types, by Burning in Large Deactivation Furnace
 - g. SOP, Demil of 120mm Cartridge Case
 - h. SOP, Defuze 120mm Projectile
103. "Report on Pilot Plant Investigation for Treatment of Explosive Contaminated Wastewater," NAD Hawthorne, Nevada, November, 1974.
104. "Project Report, Process Determination and Plant Layout for Western Demilitarization Facility, Hawthorne, Nevada," September, 1974, NAPEC, NAD Crane, Indiana.

NAVY - DAHLGREN NWSC

105. "DOD Open Burning Disposal of Waste Munitions," NWSC/DL TR-3476, NWSC Dahlgren, Va., September 1976.

NAVY - HAWTHORNE NAD

106. "Report on Pilot Plant Investigation for Treatment of Explosive Contaminated Wastewater," NAD Hawthorne, Nevada, November, 1974.

NAVY - NAVAL FACILITIES ENGINEERING COMMAND (NAVFAC)

- 107. Drawing 2014-625, Northern DIV NAVFAC, "NWSC Crane Particulate Abatement Water Flow Diagram."
- 108. Drawing 2013720, Northern DIV NAVFAC, "NWSC Crane Air Pollution Measures for Demil Furnaces."
- 109. Drawing, Northern DIV NAVFAC, "NWSC Crane TNT Waste Treatment Facility."

NAVY - NAVAL SEA SYSTEMS COMMAND (NAVSEA)

- 110. Letter, Hq. Naval Sea Systems Command, 27 January 1976, Subject: "Requirements and Guidelines for Chemical Decontamination of Projectiles and Warheads."

PERSONAL COMMUNICATIONS

- 111. Personal Communication, Anniston Army Depot Personnel, 14 July 1976.
- 112. Personal Communication, NWSC Crane personnel, May 24, 1976.
- 113. Personal Communication, NAD Hawthorne personnel, April 22, 1976.
- 114. Personal Communication, Letterkenny Army Depot personnel, 12 July 1976.
- 115. Personal Communication, Red River Army Depot Personnel, 16 July 1976.
- 116. Personal Communication, Savanna Army Depot, 26 May 1976.
- 117. Personal Communication, Tooele Army Depot personnel, 10 August 1976.
- 118. Personal Communication, Rocky Mountain Arsenal personnel, 9 August 1976.

PUBLICATIONS, GENERAL

- 119. "Measurements of Air and Ground Shock Disturbances Arising from Demolition Activities at Red River Arsenal," University of Utah, December 1957.

120. "Determination of Emission Parameters from the Deactivation Furnace," York Research Corporation, Report No. Y-8197, August 31, 1973.
121. "Proposal and Specifications, Flashing Furnace," Midland Ross, November 12, 1975, DAAG49-76-R-0008.
122. "A Study of Equipment, Processes and Systems for a Demilitarization Facility at NAD Hawthorne, Nevada," Battelle Columbus Laboratories, 31 June 1975.
123. "Concept Description, Rotary Furnace for Large Items Demilitarization," Draft Report.
124. Memorandum on Removal of TNT from Wastewater, Pittsburgh Activated Carbon Company, July 12, 1965.
125. "Equipment Concepts and Engineering Criteria for Bulk Explosives Disposal," Preliminary Draft Report, Battelle Columbus Laboratories, 31 March 1976.
126. "Adsorption Technology Applied to Wastewaters of the Munitions Industry," R. D. Heck, Mason & Hanger Co., September 1976, ADPA Symposium on Environmental Research, September 1976.
127. "The Effects of UV Light on TNT and Other Explosives in Aqueous Solution," C. Andrews, ADPA Symposium on Environmental Technology, September 1976.
128. "Soil and Ground-Water Contamination from Explosives," Dr. D. Chan, ADPA Symposium on Environmental Technology, September 1976.
129. "Economic Analysis of Interim Final Effluent Guidelines for Selected Segments of the Explosive Industry," EPA 320/1-75-065a, February 1976, U. S. EPA, Washington, D. C.
130. Unpublished Data Provided by Hq. U. S. Army Armament Command.
131. Tay Can Scientific and Engineering Services Letter to AEO, Tooele Army Depot, Utah, dated 22 June 1976.

APPENDIX
ENGLISH-METRIC CONVERSION TABLE

MULTIPLY (ENGLISH UNITS)		by	TO OBTAIN (METRIC UNITS)	
ENGLISH UNIT	ABBREVIATION	CONVERSION	ABBREVIATION	METRIC UNIT
acre	ac	0.405	ha	hectares
acre-feet	ac ft	1233.5	cu m	cubic meters
British Thermal Unit	BTU	0.252	kg cal	kilogram-calories
British Thermal Unit/Pound	BTU/lb	0.555	kg cal/kg	kilogram calories/kilogram
cubic feet/minute	cfm	0.028	cu m/min	cubic meters/minute
cubic feet/second	cfs	1.7	cu m/min	cubic meters/minute
cubic feet	cu ft	0.028	cu m	cubic meters
cubic feet	cu ft	28.32	l	liters
cubic inches	cu in	16.39	cu cm	cubic centimeters
degree Fahrenheit	°F	0.555 (°F-32)*	°C	degree Centigrade
feet	ft	0.3048	m	meters
gallon	gal	3.785	l	liters
gallon/minute	gpm	0.0631	l/sec	liters/second
horsepower	hp	0.7457	kw	kilowatts
inches	in	2.54	cm	centimeters
inches of mercury	in Hg	0.03342	atm	atmospheres
pounds	lb	0.454	kg	kilograms
million gallons/day	mgd	3,785	cu m/day	cubic meters/day
mile	mi	1.609	km	kilometer
pound/square inch (gauge)	psig	(0.06805 psig +1)*	atm	atmospheres (absolute)
square feet	sq ft	0.0929	sq m	square meters
square inches	sq in	6.452	sq cm	square centimeters
ton (short)	ton	0.907	kg	metric ton (1000 kilograms)
yard	yd	0.9144	m	meter

*Actual conversion, not a multiplier